VEGETATIONAL CHANGES ON A SEMIDESERT GRASSLAND RANGE FROM 1858 TO 1963

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INTRODUCTION

Extensive areas of the semidesert grassland of the Southwest are dominated by creosotebush (*Larrea tridentata* (DC) Coville), mesquite (*Prosopis juliflora* (Swartz) DC), and tarbush (*Flourensia cernua* DC). Mesquite occurs on 93,000,000 acres; creosotebush is present on 46,500,000; and tarbush occurs on 13,250,000 acres (Platt 1959). Although the species are indigenous, they have invaded large areas in the past 100 yrs. Some areas invaded by tarbush still have a good understory of grass. However, loss of forage production occurs in early stages of mesquite invasion (Norris 1950). In creosotebush-dominated areas, forage production is negligible (Gardner 1951).

The productivity of the rangeland greatly influences the economy of the Southwest. Therefore, it is important for the rancher to conserve and, where necessary, improve the range resource. Some knowledge of original vegetation conditions is essential in properly evaluating the potential of various sites.

Much has been written about the semidesert grassland, including quotations from many early travelers. Some authors have based general assumptions on these quotations. However, the quotations are difficult to evaluate properly. In making their observations, many early travelers were influenced by the seasons and by their personal emotions. Furthermore, very few of the areas described by early travelers can actually be relocated for present-day comparisons.

This study aims to show the degree of encroachment of brush on the study area and also the nature of the invasion on various soil types. Vegetation surveys of 1858, 1915, 1928, and 1963 were compared. Factors possibly responsible for the changes in vegetation were examined. This study was conducted on the Jornada Experimental Range, which is 23 mi north of Las Cruces, New Mexico.

REVIEW OF THE LITERATURE

Mason (1963) mentioned that early botanists most often described showy shrubs and trees instead of the grasses. Some of his observations disproved popular ideas about the productivity of the range and certain soil indicator plants. However, he suggested that historic data can be used to classify plants as increasers, decreasers, and invaders. No early observations were made specifically on the study area, but several early observers commented on the vegetation

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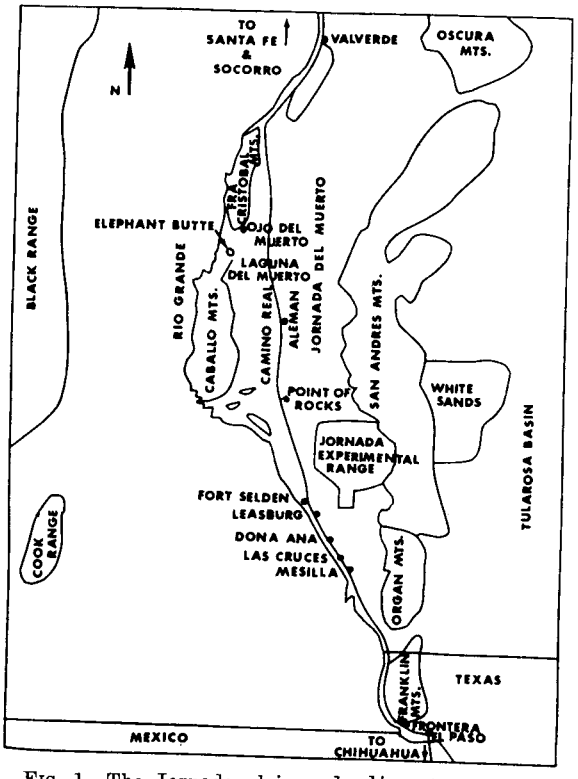

FIG. 1. The Jornada plain and adjacent areas.

in the vicinity. Figure 1 shows the Jornada plain and adjacent landmarks.

Emory (1848), on a military reconnaissance from Fort Leavenworth to San Diego, California, followed the Camino Real (the main trail from Chihuahua City to Santa Fe) from Albuquerque to the northern end of the Fra Cristobal Mountains. At that point he left the main trail and went west. As he followed the river by the Fra Cristobal Mountains, he noted what he thought were typical southern New Mexico plants: "First, there were cacti in endless variety and of gigantic size, our new and disagreeable friend the larrea Mexicana, Fremontia vermicularis, obine canescens, tessaria borealis, diotis lanata, franseria acanthocarpa, several varieties of mesquite. . . ."

He also mentioned *Dalea formosa* Torr., a species of *Malva,* and a large species of grama. The Jornada plain was shown on a map by Abert (1848) as "tablelands with grama grass but no running water." He mentioned crested quail running along in the clumps of "kreosoteplant" south of Socorro and also mesquite and *Condalia undulata* in that vicinity.

Wislizenus (1848), in his memoir of a tour to northern Mexico, stated that the principal tree in the Rio Grande Valley was mesquite. In reference to the Jornada del Muerto (the Jornada plain), August 1, 1840, he said: "In the rainy season there is generally plenty of water on the Jornada . . . . a high plain in the elevation of from 4,000 to 5,000 feet above the sea, with dry, hard soil, tolerable grasses and an abundance of mesquite and palmillas. The latter grow to a height of 10 to 12 feet."

The Laguna del Muerto (a lake) was dry, but Ojo del Muerto, located 5 mi west of the trail, was a spring where the travelers drove their 400 to 500 head of livestock to water. They saw many antelope on the way to the Ojo. *Koeberlinia* was frequently observed from south of Chihuahua to Monterrey.

Marcy (1850), crossed the Jornada plain on his way from Santa Fe to Fort Smith. He measured 77.5 mi from the point where he left the river to where he encountered it again after crossing the Jornada. Of the plain, he reported:

> "We found grass good and a small growth of scrubby brush which answered very well to cook with; but there were no trees or other vegetation except several varieties of the cactus and palmetto."

Bartlett (1854), in his narrative of experiences in Texas and New Mexico, said: "The Rio Grande Valley near El Paso and generally in other places, is thickly timbered with cottonwood. The tree sometimes grows to a large size. Mesquite is found on the border between the plateau and valley; on the plateau itself it appears in a scrubby state."

In speaking of the Organ Mountains which lie immediately south of the San Andres Mountains, Bartlett (1854) stated: "Cactaceous plants abound on these mountain sides and on the spurs leading to them. The yucca, Spanish bayonet, mesquite, larrea, and various plants peculiar to desert regions and the great plateau are found here. The lower spurs and intervening valleys are in many places covered with grama grass. The bottom lands are not grass as many suppose, but entirely bare save in a few isolated spots; hence it is necessary to drive mules and cattle to these hills and valleys to feed. There are some portions of the valley above Frontera where grazing is to be found."

In another statement, Bartlett (1854) wrote: "The Jornada del Muerto is 90 miles across without water, and of most desertlike character."

In 1846 Cooke (Cooke et al. 1938) followed the Rio Grande south rather than cross the Jornada. However, on November 3, 1846, he came in view of the Jornada which "for as far down as the eye could see was an unbroken mass of snow." He followed the river to a point about 15 mi northwest of Rincon where he turned west. In his reference to the mesa west of the river, he stated: "There was no fuel save a few bushes and Spanish bayonet. The country was well covered today with grama grass, and also I saw buffalo grass."

As his party traveled westward, Cooke saw some antelope. Early travelers in south-central New Mexico quite often noted buffalo grass in the vicinity of prairie dog towns. There is no *Buchloe dactyloides* (Nutt.) Engelm. present on the Jornada plain, and it

is thought that they may have been referring to burrograss (*Scleropogon brevifolius* Phil.).

In 1857 Stacy (1929), on his journey with Beale, encountered rain on the way from the river to the Jornada plain. This may have had some effect on him when he observed: "Nothing could exceed the beauty of the country we traveled over this morning. The whole extent, as far as vision reached ahead, was a level plain, covered thickly with the most luxurious grass, and filled with beautiful flowers. . . . Hundreds and hundreds of thousands of acres, containing the greatest abundance of the finest grass in the world, and the richest soil here lying vacant, looked upon by the traveller with dread, because of its want of water."

Stacy's party camped that night without water; however, it rained during the night. They traveled only 4 mi the next day, as they found water at Aleman. After they reached the river again, they made their camp on the hills nearest to the river, as "we found excellent grass." He noted that the grass in the valley was poor. (At the present time the hills nearest the river generally have no grama grass and are nearly bare except for creosotebush.)

Emory (1857) stated in reference to the southwestern United States: "Most of these plains were covered with a luxuriant growth of grama, the most nutritious of all grasses. Sometimes they were destitute of all vegetation except *Larrea mexicana,* the yucca, the cactus, and other spinous plants and are paved with minute fragments of chalcedony, basalt, agate, and other hard rocks. Occasionally in these plains we encounter sand-dunes, called by the Spanish, "Medanos," extending over large areas of country encircling what might at first sight be supposed the shores of dried up lakes."

Along the Mexican border, he reported that mile after mile of mesa supported an excellent stand of black grama (*Bouteloua eriopoda* (Torr.) Torr. and a stunted stand of creosotebush, mesquite, yucca (*Yucca elata* Englm.), and ocotillo (*Fouquieria splendens* Engelm.). He said that the stockmen were experiencing drought which was aggravated by the overgrazing that prevailed in 1859. The drought and the price of silver at that time caused the area to be in a depressed state.

Parry (1859), writing on the vegetation of the El Paso basin and the upper Rio Grande Valley, said that it was much different in the valley than it was on the tablelands. He stated: "Upon the tablelands which spread out beyond the mountain barrier, the eye falls upon a great variety of plants, none of which are seen in the more fertile valley. Among these are *Fouquieria splendens, Larrea mexicana, Flourensia cernua, Rhus microphylla, Condalia obovata, Koeberlinia spinosa* and species of *Krameria, Ephedra,* and *Yucca.* The margin of the tableland, where it borders upon the valley, is broken by deep ravines, and we find upon the sandy bluffs a growth of chaparral, made up principally of mesquite and the equally thorny acacias."

He said that the main grasses belonged to the genera *Chondrosium* and *Bouteloua.*

Fountain (1885), in a bulletin distributed to interest people in settling in Dona Ana County, mentioned that the Jornada plain was treeless and almost waterless but covered with rich, nutritious grass. He said that profits from cattle or sheep raising should average 30% annually. He also mentioned that if a person were unsuccessful in mining or raising livestock, he could always cut, bale, and sell grama grass from the Jornada plain.

Other travelers and botanists passed through the Southwest, but those mentioned above actually referred to the Jornada or places near it.

Branscomb (1956), in a study of shrub invasion on the Jornada Experimental Range, found that from 1915 to 1946 the area of grassland decreased 12%, mesquite-dominated areas increased 20%, and tarbush-creosotebush areas decreased 2%. Broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. & Rusby) dominated areas decreased 6%.

Wright (1960), in a study based on vegetation on the New Mexico Agricultural Experiment Station Ranch, which lies adjacent to the Jornada Experimental Range, found that the crown spread of mesquite increased under complete protection as well as under livestock use. Brown (1950), conducting studies on the Santa Rita Experimental Range in Arizona, showed that mesquite, once established, will increase in density and invade adjacent areas under all systems of management. Glendening (1952), in a 17-year study on the Santa Rita Experimental Range, found that mesquite had increased more on protected plots than on those subject to grazing by livestock. Norris (1950), reporting on a 8-year study of the effects of rodents, rabbits, and cattle on two vegetation types of semidesert grassland, found that in mesquite-snakeweed types rodents and rabbits alone exert sufficient grazing pressure to prevent vegetation improvement. In well-preserved black grama grassland, there are relatively small numbers of rodents and rabbits.

Lohmiller (1963), after a study of rainfall and forage data, stated that drought is a major factor in reducing the stand and production of perennial grasses in wide areas of the Southwest. Records from the New Mexico State University weather station indicate that the 1947 to mid-1957 drought was the most severe ever recorded at that station. These records were initiated at Army posts along the Rio Grande River in 1851. Schulman, reported by Humphrey (1958), concluded that it is likely that the drought of the 1950's was the most severe experienced in the southwestern United States since the late thirteenth century. According to Branscomb (1956), a definite cyclic pattern exists in the record of precipitation in southern New Mexico. He noted five cycles as being evident in records of New Mexico State University and vicinity.

According to Parker & Martin (1952), drought reduces grass cover. This reduction may permit mesquite seedlings to become established during periods of more favorable moisture. Once established, mesquite is able to compete very well with the grasses. During periods of extended drought, grasses make little growth and in many instances are completely killed. It is the opinion of Bogusch (1952) that climatic fluctuations have far less influence in initiating brush invasion than they do in perpetuating it. Favorable moisture conditions are required for early development of the woody plant seedling since they are no less vulnerable to drought than are the grass plants. After the brush becomes established, it is better able to compete successfully with the grass for deep moisture.

Jardine & Forsling (1922) stated that by 1910 southwestern ranges were fully stocked and that there were no unstocked ranges to use in case of drought. In their study of the 1916 through 1918 drought, they found that on ungrazed range basal area of grasses decreased by 40%, whereas on ranges grazed heavily throughout the year grasses decreased 62 to 70% in basal area. Grasses on properly grazed range decreased in basal area as much as 45%. They concluded that once soil moisture reaches a certain low point, grasses under protection cannot survive any better than those being grazed.

Gardner (1951), in his study of the Rio Grande Valley in southern New Mexico, found that creosotebush appeared to have been present originally on the gravelly ridges and apparently moved from these ridges down into adjacent grassland. The presence of younger plants along the grassland border supported this conclusion. To Gardner (1951), creosotebush appeared to be the best adapted of any shrub he studied.

In his observations on tarbush types, Gardner (1951) found that creosotebush was invading the areas previously dominated by tarbush. On areas dominated by tarbush, the average grass cover was far greater than that on the creosotebush sites. It appeared that on the areas where grass was decreasing, all ages of tarbush plants were observed. On areas where there was a heavy stand of creosotebush, only old tarbush plants were present.

Fosberg (1940), studying the flora 25 mi south of the Jornada Experimental Range, found that creosotebush reaches its best development on the limestone alluvial fans. On the hills of coarse alluvium mixed with silt that form the terraces, creosotebush was sparse. He reported that there was a sharp division between the creosotebush type on the limestone alluvium and the black grama grasslands on the porphyritic alluvium.

MATERIALS AND METHODS

Description of Study Area

Physiography. The Jornada Experimental Range is included in the area described by Merriam (1898) as the Lower Sonoran Life Zone. It was classified as Desert Plains Grassland by Clements (1934). It is located on the Jornada del Muerto plain, which is bounded by the San Andres Mountains on the east and by the Rio Grande Valley and the Fra Cristobal-Caballo Mountain complex on the west. Elevation varies from 3,900 to 4,500 ft. The Jornada plain consists of unconsolidated Pleistocene detritus (Veatch 1918). This alluvial fill from the nearby mountains is 300 ft thick in places and the aggradation process is still active. Coarser materials are found near the foothills along the eastern part of the study area, and the finest materials are found in the lowest areas. The topography of the study area consists of gently rolling to nearly level uplands, interspersed with swales and old lake beds.

On the Jornada Experimental Range, 105,700 acres are used for grazing. An additional 38,775 acres, originally included in the grazed area of the range but now under lease to White Sands Missile Range, was also used in this study. The latter area has not been grazed by domestic livestock since 1953. The portion of the Jornada Experimental Range in the San Andres Mountains and foothills, also under lease to White Sands Missile Range, was not included in this study because no early vegetation data were available on that area.

Climate. The climate of the Jornada Range is typical of the arid phase of the semidesert grassland. There is an abundance of sunshine, a wide range between day and night temperatures, low relative humidity, and extremely variable precipitation. Most winter moisture comes as low-intensity rains or occasionally as snow. Most summer precipitation comes as localized thunderstorms of high intensity.

Rainfall records have been kept at the Jornada Experimental Range since 1915. The average annual precipitation at the Range Headquarters from 1915-1962 was 9.10 in. Of the annual rainfall 52% occurs between July 1 and September 30. However, rainfall is often quite erratic during the growing season (Paulsen & Ares 1962).

Rainfall is often poorly distributed around the area. For example, in 1962 the precipitation at Jornada headquarters was 14.89 in., one of the highest since records have been kept. That same year the State University, less than 30 mi southwest, recorded only 6.39 in.

In more humid areas, temperatures usually determine the length of the growing season. This does not follow for arid areas. The temperature may be favorable for plant growth about 200 days, but moisture conditions are such that normally growth occurs only from 90 to 100 days. The average maximum temperature is highest in June when it averages 97° F; it is lowest in January when the average maximum is 56° F.

Wind movement is greatest in April and May and least in December. Evaporation averages 92.6 in. annually. The greatest evaporation occurs in June, when it exceeds 13.5 in. The growing season, when

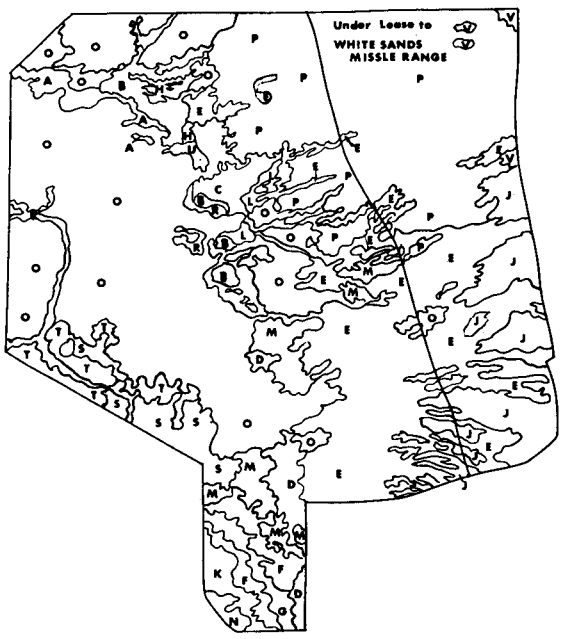

FIG. 2. Soils of the Jornada Experimental Range (Soil Conservation Service, 1963).

both precipitation and temperature are favorable, is July through September. At this season wind movement is not great.

Principal Plant Species. The main grass species on the study area are black grama, mesa dropseed (*Sporobolus flexuosus* (Thurb.) Rydb.) and *Aristida* spp. growing on the sandy upland sites. In the lower-lying areas, the main forage species are tobosa (*Hilaria mutica* (Buckl.) Benth.), and burrograss. The main browse plant is fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.), which normally occurs in association with mesquite (*Prosopis juliflora* (Swartz) DC. var. *glandulosa* (Torr.) Cockerell), creosotebush, and tarbush. Other shrubby plants are yucca and broom snakeweed.

Soils. The Soil Conservation Service recently completed field work on a soil survey of the area presently being grazed on the Jornada Experimental Range (105,700 acres). The complexity of the soils is shown in Figure 2. The area under lease to White Sands Missile Range was mapped for soil type by the SCS Soil Scientist who mapped the area presently being grazed. He used aerial photos, the 1963 vegetation descriptions, and the 1918 soils map (Veatch 1918).

The soils listed below are generally arranged in the order of soil texture with the "A" soil being the heaviest. Names used in describing these soils are tentative, pending final correlation. The soils were described as follows (Soil Conservation Service, 1963):

A. Verhalen clay, 0 to 1% slopes.—Deep to moderately deep, poorly drained, calcareous clays which contain appreciable quantities of readily soluble salts. Gypsum crystals are found throughout the profile. Often underlain by massive deposits of gypsum at depths below 20 in., they are developing in old lake bottoms and much of their area is barren. In other places, tobosa and alkali sacaton (*Sporobolus airoides* (Torr.) Torr.) clumps grow on pedestals of soil up to 2 ft high.

B. Russler loam, 0 to 3% slopes.—Fine-textured, moderately deep to deep, poorly drained, strongly calcareous soils; similar to "A" except that they contain more gypsum throughout the profile and are generally less deep. Present vegetation is tobosa, gypgrass (*Sporobolus nealleyi* Vasey), burrograss, scattered mormon tea (*Ephedra* spp.), and yucca.

C. Cottonwood-Reeves-Hoban complex, 0 to 3% slopes —A complex of calcareous-gypsiferous soils ranging in depth from a few to as much as 40 in. The principal soils are less than 10 in. deep over gypsum and comprise about 50% of the mapping unit. The remaining soils, deep to moderately deep to the gypsum layer with moderately fine-textured profiles, generally occur on slightly concave, nearly level to gentle slopes. Main vegetation present on the very shallow soils is gypgrass and mormon tea; on deeper soils burrograss, tobosa, black grama, and yucca may be present.

D. Hoban silt loam, 0 to 1% slopes.—Moderately deep to deep, light-colored, calcareous soils that have a silty surface and moderately fine-textured, slowly permeable subsoils. Moderate to strong lime (calcium carbonate) zones usually occur at depths of 20 in. and below. Occur in the lower parts of the Jornada basin and receive some flood water during extreme thunderstorms. Present vegetation is mainly burrograss, tarbush, and crucifixion thorn (*Koeberlinia spinosa* Zucc.).

E. Dona Ana complex, 0 to 3% slopes.—The principal soils of this mapping unit are deep and calcareous with medium-textured surfaces over weakly developed, moderately fine-textured, slowly permeable subsoils. Prominent horizons of calcium carbonate accumulations occur below 25 in. The landscape is traversed by a series of erosional escarpments which range in height from 6 in. to as much as 7 ft. In many places at the foot of the escarpments accumulations of sand have formed a narrow, sandy ridge varying from a few inches to several feet thick over fine underlying material. The sand ridges, about 5 to 30% of the mapping unit, support mainly tarbush. Between the scarps, burrograss and tobosa grow in association with tarbush. The sandy ridges below the scarps have tarbush, mesquite, and in some areas alkali sacaton. On the southern part of this mappnig unit there is a sizeable amount of creosotebush at the higher elevations. Small inclusions of "J" soils are present within the "E" soils in that area.

F. Continental loam, 0 to 3% slopes.—Deep to moderately deep soils with medium-textured surfaces over well-developed, clayey, slowly permeable subsoils. Strong lime zones occur below 26 in. They are associated with the lower lying soils of the Jornada basin and may occasionally be flooded by runoff water from higher areas. The present vegetation is made up of tarbush, burrograss, tobosa, crucifixion thorn, three-awns, and creosotebush.

G. Continental silt loam, bolson phase, 0 to 1% slopes.—Similar to "F" soils except for their thicker subsoils and greater depth to the lime zone. They occur in a long, narrow strip 1/10 to ½ mi wide in the lower part of the southern portion of the study area. Runoff from the higher adjacent slopes provides extra water which supports abundant stands of tobosa with lesser amounts of burrograss and tarbush.

H. Cottonwood-gypsum outcrop complex, 0 to 3% slopes.—These soils are very shallow, medium-textured, strongly calcareous, overlying gypsum beds which are exposed on the surface in places. Occupying ridges and knolls, the relief is convex, drainage is good, and sheet erosion is severe. They support gypgrass and mormon tea. Some deeper inclusions support mesa dropseed, burrograss, yucca, and black grama.

J. Cave gravelly sandy loam, 2 to 5% slopes.—Mostly shallow, with a gravelly surface and moderately coarse-textured subsoil; developing on alluvial fans derived mostly from limestone and calcareous sandstone. Highly calcareous and underlain by cemented limestone cobble or indurated caliche. Occupy long ridges that slope down to the "E" soils. In many places the gullies have been eroded to caliche or the limestone cobble. The main vegetation present is creosotebush, with lesser amounts of mesquite and tarbush.

K. Daggett gravelly sandy loam, 1 to 3% slopes.—Deep, gravelly, moderately coarse-textured, rapidly permeable soils that occupy alluvial fans near the Dona Ana Mountains. In many places the surface is covered with a gravel pavement. Paleosols are frequently encountered at depths from 32 to 74 in. below the surface. The present vegetation consists of creosotebush, tarbush, fluffgrass (*Tridens pulchellus* (H.B.K.) Hitchc.), yucca, and mormon tea.

L. Gomez sandy loam, 0 to 7% slopes.—Deep, well to imperfectly drained, calcareous soils, with moderately sandy surfaces over grayish subsoils of sandy clay loam; on gentle slopes of playas or depressional areas, usually on the leeward side. The subsoils often show signs of mottling due to poor drainage. Gypsum beds frequent below 40 in. The present vegetation consists of mesquite, broom snakeweed, yucca, dropseeds (*Sporobolus* spp.), black grama, and some tobosa.

M. Turney sandy loam, 1 to 3% slopes.—Deep to moderately deep, light-colored, calcareous soils with sandy surfaces over weakly developed, moderately permeable, sandy clay loam subsoils. A prominent lime zone usually occurs below 20 in. Sandy soils subject to wind erosion; surface soils wind-shifted in many places. Mesa dropseed, broom snakeweed, black grama, and mesquite make up the present vegetation.

N. Cavot very gravelly sandy loam, 2 to 5% slopes.—This soil, of small acreage in the study area, is a shallow to moderately deep, gravelly, sandy loam, underlain by caliche at depths of 10 to 32 in. Sheet and gully erosion are active. Creosotebush with some old mesquite plants make up the present vegetation.

O. For purposes of this study, three soil types are combined. Prior to mesquite invasion and subsequent wind erosion, these soils were similar. They have been re-divided in this study on the basis of the origin of their substrate. The "O" soils in this study comprise the lower part of the area and are aeolian sands over basinal deposits and soils.

Banbar loamy fine sand, 1 to 3% slopes.—Restricted to the basinal portion of the study area; deep, with moderately sandy surfaces over reddish, moderately permeable, sandy clay loam subsoils. Accumulations of lime frequent at depths below 16 to 20 in. Very susceptible to wind erosion, and if invaded with mesquite, coppice dunes usually begin to form. The present vegetation consists of mesa dropseed, black grama, broom snakeweed, and lesser amounts of mesquite and yucca.

Banbar soils, hummocky, 1 to 3% slopes.—The soils of this mapping unit are the same as above, except being damaged by wind erosion to which they are extremely susceptible. Sand hummocks from 1 to about 3 ft in height occupy 20 to 50% of the mapping unit. Presently these soils support dropseeds, yucca, mesquite, and broom snakeweed.

Coppice duneland, 1 to 3% slopes.—Coppice sand dunes, 3 to 8 ft in height, with barren blown-out areas between the dunes are the prominent features of this mapping unit which comprises 40 to 55% of the area. In most instances, the sand dunes have formed around mesquite or other woody plants. Between the intermittent dunes, the soils range from deep to very shallow over indurated caliche. The present vegetation is mesquite with lesser amounts of fourwing saltbush and occasionally yucca.

P. These soils make up the higher parts of the latter two soil types (Banbar soils, hummocky and copice duneland) and were mapped as Goldenberg sands on the 1918 soil survey (Veatch, 1918). They are

aeolian sands over piedmont deposits and soils. They differ from the "O" soils in that a caliche layer is absent in most places, and where it is present it is much less developed. The "P" soils appear to have larger, older sand dunes than the "O" soils. They also appear to be somewhat deeper than the basinal soils. The ruins of an Indian pueblo are present on the eastern part of this area. Since Pueblo Indians usually conducted farming operations, it may be assumed that portions of this area were farmed. It was abandoned by the Pueblo Indians between 1275 and 1300 (Martin *et al.* 1956). The "P" soils presently have a greater amount of fourwing saltbush, sand sagebrush (*Artemisia filifolia* Torr.), tarbush, and creosotebush present than do the "O" soils. Mesquite sand dunes are present on both "O" and "P" soils.

R. Palma loamy fine sand, 3 to 6% slopes.—Deep soils with sandy surfaces over rapidly permeable, moderately sandy subsoils. Weak to moderate accumulations of lime usually occur below 35 in. Occupy long, narrow, sloping ridges that border the "O", "S", and "T" soils. Subject to wind erosion, but sand accumulations are generally less than 18 in. over the underlying soil. The present vegetation is mesquite, yucca, dropseeds, and black grama.

S. Cacique loamy fine sand, 1 to 3% slopes.—Mostly moderately deep soils with moderately sandy textured surfaces with permeable subsoils that take water well. The soils are underlain with discontinuous layers of indurated caliche. In many places, due to rodent activity, caliche fragments have been mixed throughout the soil profile. The present vegetation is black grama and yucca with broom snakeweed and mesquite on deteriorated areas.

T. Simona-Palma complex, 0 to 3% slopes.—Soils with sandy surfaces over weak to moderate lime zones that may be discontinuously indurated. The principal soils are calcareous to very near the surface and are underlain with fractured, indurated caliche at depths of 10 to 24 in. These soils comprise about 50 to 60% of the mapping unit. The other soils are moderately deep to deep, usually non-calcareous to about 15 in., with weakly developed, rapidly permeable subsoils over weak to moderate accumulations of lime. Caliche gravels and fragments have been mixed throughout the soil profile by rodents in most areas. The present vegetation is black grama and yucca with some mesquite.

U. Cottonwood fine sand, 0 to 3% slopes.—These very shallow to shallow sandy soils overlie gypsum beds at depths ranging from about 4 to 24 in. or more (aver. about 16 in.). In barren blowout areas the gypsum is exposed on the surface. Wind erosion is active, and as a result the sandy surface soils are constantly redistributed. Vegetation is nearly lacking in the blowouts, but in depressions where drainage is poor the vegetation is made up of burrograss, tobosa, and mesquite. Outside the depressions three-awns, dropseeds, yucca, and broom snakeweed are present in small quantities. Broom dalea (*Dalea scoparia* A. Gray) and mormon tea are present on the deeper sand.

V. Rock outcrops.—Comprise less than 0.1% of the study area. Much of the surface is bare rock. In some areas, sand has accumulated quite high on the slopes and covers, or partially covers, the rock. The main vegetation present is creosotebush, mesquite, ocotilla, and *Yucca* spp. On north slopes, grasses may be present.

HISTORY OF LIVESTOCK USE

The Jornada plain has had a vivid history since before 1680, when it was given the name "Jornada del Muerto," often translated as "Journey of Death" or "the Journey of the Dead One," by Spaniards fleeing attack by Indians during the Indian Rebellion of 1680.

As soon as New Mexico was claimed by Spain, people traveled across the Jornada plain enroute from Chihuahua city to the capital at Santa Fe. The Rio Grande River bends to the west and the Caballo Mountains lie close to the river on the east, so travel along the river was dangerous. It was for this reason that travelers left the valley, crossed the Jornada plain, and traveled 76 mi without water to bypass the obstacle and also to escape Indian ambushes. There was one main spot located along the trail in which considerable water would accumulate after rains. This spot was near a place called Aleman, where three Germans were killed. This trail from Chihuahua to Sante Fe across the Jornada was called the "Camino Real," meaning literally the "King's Highway." Great herds of sheep, goats, cattle, and horses were driven along the route, although there were no livestock operations at that time on the Jornada plain itself. The Camino Real was west of the study area. This trail can be located easily by the presence of mesquite dunes. The dunes did not spread much from the trail area until the last 20 yrs.

In 1858, when the study area was first surveyed by the United States General Land Office, the surveyors mentioned that the farmers in the valley put cattle up on the plain near the mountains for summer grazing because of available spring water. They had no fences in the valley; therefore, cattle were driven to the Jornada to prevent damages to crops. Bartlett (1854) mentioned this also when speaking of the forage conditions in the Rio Grande Valley.

There were several springs in the San Andres Mountains which border the Jornada on the east. They were of sufficient size to be of value for stock raising purposes. Some of the numerous mining claims staked in the San Andres were later converted to cattle and goat ranching operations. It was not until about 1870 (Bowman 1888) that a well was dug

at Aleman, on the old Camino Real, on the Jornada plain for use by travelers and stagecoach horses. When Eugene Rhodes first came to the Engle area in 1881, he worked for a Kentucky syndicate which ran short-horned Durham cattle. One of his first jobs was to recurb the old well at Aleman which measured 4 ft wide, 6 ft long, and 160 ft deep.

Little is known about the amount of usage of the Aleman well prior to that time. Bill McCall, of Radium Springs, New Mexico, an oldtime cowboy on the Jornada plain, stated that on his arrival in 1884 there were "worlds of cattle" along the west side of the Jornada plain.[3] Evidently this was during the big increase in cattle numbers. Bancroft (1889) said that the numbers of cattle in Socorro County increased from 9,000 to 70,000 head between 1882 and 1884. Socorro County previously included that part of Sierra County just north of the study area. Bill McCall said that the cattle watered at the river and then moved back onto the plain to graze. Few cattle got as far east as the three main lakebeds which caught and held water. One lakebed, Red Lake, is on the present Jornada Experimental Range (previously the Jornada Range Reserve). Cattle along the west side of the plain were owned by many different people.

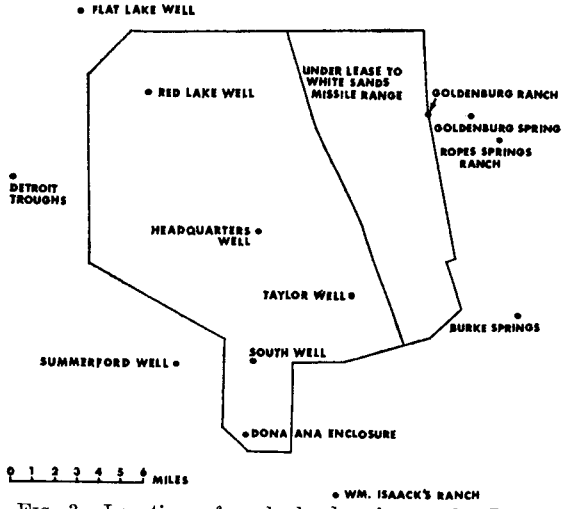

FIG. 3. Location of early landmarks on the Jornada Experimental Range and vicinity.

In 1883 the Goldenburg brothers, Hugo, Max, and Alex, started a ranch at a spring in the San Andres Mountains. The location of this ranch is shown in Figure 3. In 1887 they were forced to move because of constant pilferage by Indians. They moved about 2 mi west of the spring to a site on the edge of the mountains where they built a large adobe house. Their cattle were pushed far out on the sands to graze. Many went as far west as Flat Lake, about 15 mi from the mountains, or some 2 mi from the northwest corner of the Jornada Experimental Range.

[3] Interviews with Bill McCall on June 26 and December 26, 1963.

About 1.5 mi south of the Goldenburgs, Horace Ropes took over a mining claim and spring and brought 500 head of cattle from Arkansas in 1885. Ropes had concrete pipe, flume, and ditches constructed 3 mi toward the flats. The pipeline lasted only a couple of years because the growing mesquite roots broke it up. Ropes's cattle ranged nearly to the Rio Grande River. He sold out to the Goldenburgs in 1893. McCall helped to gather 1,800 head of cattle on the Goldenburg ranch in 1900. These seem to have been the main sources of grazing pressure along the east side of the Jornada.

A group of Army officers from Michigan formed the syndicate called the Detroit and Rio Grande Livestock Company about 1886. They bought out Kim Ki Rodgers, for whom the western writer Eugene Rhodes had worked. One of Rhodes's jobs was cutting hay on the Jornada plain with a mowing machine. This would indicate either that stocking was not too great or that areas were mowed which were not accessible to livestock. The Detroit outfit bought 4,000 head of cattle from Joe Nations of Rincon. By natural increase and also by buying additional animals, the Bar Cross, as the Detroit syndicate was called, built up a herd estimated at 20,000 cattle, 1,000 of them being bulls. They ran their cattle, which had been bought from many sources, under 20 brands. In 1888 they built a tank on the western edge of the Jornada plain and pumped water from the river to the tanks. The water then flowed, by force of gravity, to Detroit Troughs, 6 mi out on the plain to the east, or about 3 mi west of the Jornada Experimental Range boundary. Bar Cross had control of most of the present Jornada Experimental Range until sometime before 1903. They ran on an area about 55 to 65 mi long and up to 30 mi wide. There may have been other small ranches there also, but no information is available on other ranchers except Ropes and the Goldenburgs.

In 1903, William Isaacks drilled a well about 10 mi southeast of the present Jornada South Well. This water probably affected the grazing pressure on a small portion of the Jornada. Later in 1903, Foster and Garrett drilled two wells on the Jornada Experimental Range for Harve Ringer. These wells were Red Lake Well and Headquarters Well. In 1904, South Well was drilled. Summerford Well, located 3 mi west of South Well, was drilled sometime prior to 1905. About 1,400 head of Summerford cattle were running on the southwestern part of the Jornada and adjoining range.

Charles T. Turney bought the three wells on the Jornada Experimental Range from Harve Ringer in 1904, and in 1905 he bought the Taylor Well, which had been drilled in 1904. Turney had 1,500 head of cattle shipped in and trailed in 1,500 head more from Texas. In 1906 another well was drilled about 2 mi northwest of the present boundary at the Flat Lake Ranch. Water was pumped by steam engine with mesquite roots as fuel.

The Jornada at that time was not fenced; therefore, cattle which watered at nearby wells grazed on the Jornada Experimental Range. By 1912, Turney had bought most of the deeded land and improvements within the present Jornada. At that time, with Turney's concurrence, the Jornada Range Reserve was created by Executive Order. E. O. Wooton of the Bureau of Plant Industry was instrumental in recommending the establishment of this experimental range. Turney fenced the area immediately and retained grazing privileges until 1925.

From May, 1915, to May, 1916, the average number of stock grazing on the Jornada Range, including weaned calves and horses, was 4,632 head on about 192,000 acres. Jardine & Hurtt (1917) reported that this level was probably too high but thought that no supplemental feed would be needed if only 4,000 head were stocked.

According to Paulsen & Ares (1962), the average number of animal units grazed on the Jornada from 1916-1926 was 2,340. A reduction was made in stocking and the 1928-1937 average was 1,272 animal units. The stocking rate was further reduced to 1,006 animal units per year for the 1941-1947 period. In 1953, with the advent of the White Sands Missile Range to the east, the Jornada was reduced to 105,700 acres for grazing purposes.

PROCEDURES

Vegetation categories. Only changes in areas of mesquite, creosotebush, and tarbush were considered in this study. Eight categories were established as follows:

0. No mesquite, creosotebush, or tarbush.
1. Mesquite.
2. Mesquite-creosotebush.
3. Creosotebush.
4. Creosotebush-tarbush.
5. Tarbush.
6. Tarbush-mesquite.
7. Tarbush-mesquite-creosotebush.

The mixed brush categories were analyzed individually on the basis of the total amount of brush. If a sub-dominant brush species was present in the amount of 12% or more, that species was included with the dominant, thereby making the area a mixed-brush category.

Species composition classes. The various brush categories were further divided into three classes on the basis of composition, as follows:

A. Sparse brush, 1 to 15% of the total plant composition, disregarding annuals. This category was used for the 1858 survey when the surveyors used the term "few."

B. Moderate brush, 15 to 55% of the total perennial plant composition. This category was used for the 1858 survey, when the surveyors said grass was "good" but "some" of the brush species were present. The highest percentage of brush considered in a moderate category was 55%. When it makes up over 55% of the total plant composition, the site is generally dominated by the brush. The moderate category of 15 to 55% was used to indicate an intermediate amount of brush, whereas 15% was used to keep the lowest category within a range where the brush would not have a great influence on the site.

C. Abundant brush, 55 to 100% of the perennial plant composition. Sand dunes were included in this category. This category was used in the 1858 survey when the surveyors said the grass was "poor" and brush was abundant.

1858 Survey. Notes on vegetation, soil, and topography were taken from the original Land Office Survey of 1858. These included all of the section lines on the study area. An example of the type of notes used in interpreting the vegetational cover is shown in a photo of an original write-up (Fig. 4). The interpretation of these notes required an extensive review of early literature to interpret common names correctly.

The most common terms used in the 1858 survey were "good grass" and "good grama grass." It is reasonable to assume that the surveyors were referring to black grama when they mentioned grama grass. However, some of the early Arizona writers used different common names than we use today.

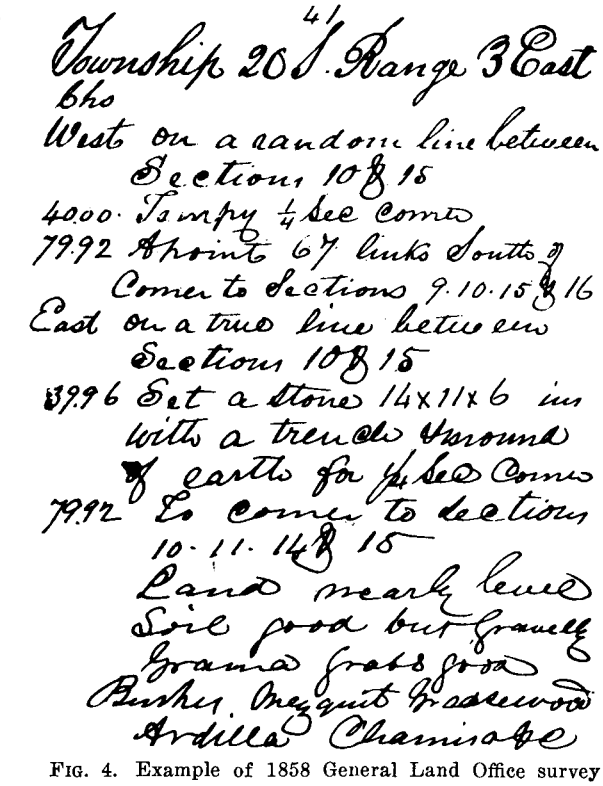
Township 20 S. Range 3 East
6ho
West on a random line between
Sections 10 & 15
40.00 Temp ¼ Sec Corner
79.92 A Point 67 links South of
Corner to Sections 9. 10. 15 & 16
East on a true line between
Sections 10 & 15
39.96 Set a stone 14 x 11 x 6 ins
with a trench around
& earth for ¼ Sec Corner
79.92 To corner to Sections
10. 11. 14 & 15
Land nearly level
Soil good but gravelly
Grama Grass Good
Bushes, Mezquit, Creosote
Ardilla Chamisal

FIG. 4. Example of 1858 General Land Office survey notes.

Griffiths (1904a) stated in reference to Arizona ranges: "The most important nutritious grasses which predominate on the open mesa range land are black grama *(Hilaria mutica), H. jamesei,* curly mesquite *(H. cenchroides),* blue grama *(Bouteloua oligostachya),* low grama *(B. polystachya),* wooly-foot *(B. eriopoda)."* In another bulletin, Griffiths (1904b) made this statement: "Confined mainly to the loose sands in the vicinity of washes, but also at times extending over portions of the rocky hillsides, is a scattering growth of *Bouteloua vestita* while *Muhlenbergia porteri,* the black grama of this region is invariably limited to the protection of cat-claw and other spiney or thorny shrubs." And later in the same bulletin, he said: ". . . upon the mesa swales galleta *(Hilaria mutica)* is an important grass."

Wooton (1916) mentioned that what was called "black grama" in Arizona was not a member of the *Bouteloua* genus but was *Muhlenbergia porteri* Scribn. He referred to *Bouteloua eriopoda* as wire grass and *Aristida* spp. as needlegrass.

Judging from the foregoing comments, we can assume that when the surveyors called something "grama grass," the term was not confined to black grama. Thus, "grama grass" was probably used as a general term which included most of the other grasses.

On shallow soil the surveyors frequently included the term "greasewood" in describing the vegetation. Bartlett (1854) mentioned the "kreosote-plant" which had a disagreeable odor. Emory (1848) said, ". . . our new and disagreeable friend the larrea Mexicana." Wooton & Standley (1915) listed "greasewood" as a common name for *Larrea tridentata* and it is so considered by some of the local people. For the purpose of this study, greasewood is considered *Larrea tridentata.*

"Ardilla," a Spanish word meaning squirrel was frequently used in the surveyors' notes. "Squirrel bush" was also mentioned. A thorough search in early records and history failed to find mention of "ardilla" or "squirrel bush." However, from the distribution and information obtained from the later surveys, it is reasonable to assume that it was tarbush. Tarbush was not mentioned by any of the early travelers across the Jornada plain whose reports were reviewed, but it was reported in the Mexican Boundary Survey (Torrey 1859), which listed the distribution of *Flourensia cernua* as "from the Pecos and Eagle Pass, on the Rio Grande, to the Mimbres, etc; sometimes covering large tracts of ground in villages and mesquite bottoms" (Schott.).

Squawbush was present in some areas where tarbush is adapted, but it is doubtful that it would be in the proportions mentioned by the survey party. Crucifixion thorn is also adapted to tarbush sites. At that time it apparently had the quite well-established name of "junco." Crucifixion thorn was described and called "junco" by several early travelers whose reports were reviewed in this study. If "junco" was an established common name, the surveyors would probably have used it to describe crucifixion thorn. For purposes of this study, "ardilla" is assumed to be tarbush. It is inconceivable to the authors that there would be an absence of tarbush on the study area in 1858.

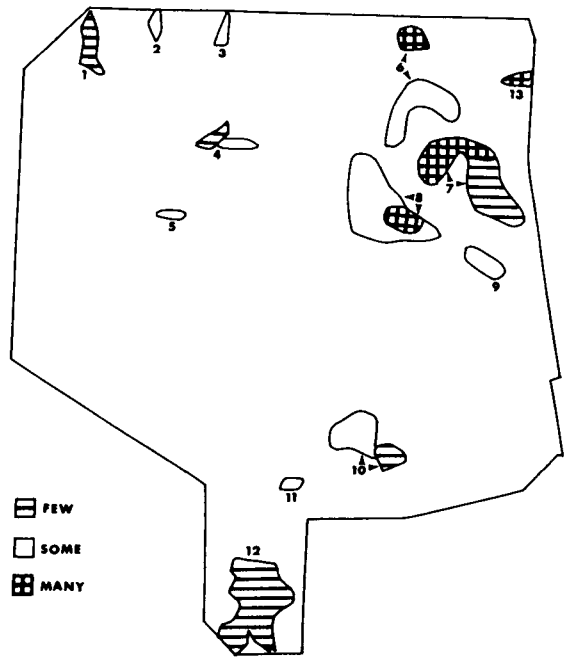

FIG. 5. Areas of unidentified brush species by abundance classes in 1858 on the Jornada Experimental Range.

After identifying the common names and terms, a map was constructed by recording the plants listed on the appropriate section line. In some instances, the surveyors mentioned a change in vegetal cover, soil conditions, and topography at a certain point on a section line. The surveyors in some instances mentioned brush which they did not identify. These areas are shown in Figure 5.

A vegetation map (scale equals 2 in. per mi) was constructed, using the map having species recorded on the section lines. With the aid of the 1915 and 1928 vegetation maps, type lines were drawn for the identified species. The areas having unidentified brush species were classified on the following basis, with the areas corresponding in number to those shown in Figure 5:

1. "Grass good, very few bushes." Mesquite, mormon tea, and yucca are present on nearby areas. No cresotebush or tarbush was present in the 1915 or 1928 survey. Therefore, it was classified as a few mesquite (category 1A).

2. "Some bushes." These areas had mesquite and tarbush present in later years so it was classified as a moderate stand of tarbush-mesquite (category 6B).

3. "Bushes greasewood, mesquite, etc." Mention is

made of mormon tea and yucca in adjacent areas. Tarbush was present in 1915 so was classified as a moderate stand of tarbush-mesquite-creosotebush (category 7B).

4. "Very few bushes, some palmia." Mesquite was the only shrub present in 1928 so it was considered an area of a few mesquite (category 1A).

5. "Some bushes, some palmia." Same as area 4 but was considered moderate mesquite (category 1B).

6. The northern part of this area was described as "sandy and very bushy" and with "grass in spots on the south and very good mesquite and palmia." Tarbush was present in 1915 and 1928. Creosotebush was nearby so this area was classified abundant tarbush-mesquite-cresotebush (category 7C).
   The southern part of 6 was "growth mesquite, sedge, small bushes and good grama grass." The small bushes were considered to be mainly snakeweed, as no tarbush was present in later surveys. It was classified as a moderate stand of mesquite (category 1B).

7. The northern part of 7 was described as "bushes abundant." Ardilla, creosotebush, and mesquite were mentioned on adjacent areas (category 7C). The southern part of 7 had "few bushes" and "very few small bushes." The three main brush species were present nearby so it was classified 7A.

8. The western part was "mesquite, chamiza, etc." Ardilla and creosotebush were mentioned nearby so this part was classified as 7B. The eastern part of the area was "abundant bushes"; the same reasoning as above was followed in classifying this 7C.

9. "Mesquite, greasewood, etc." Ardilla was present nearby so this area was considered to be a moderate stand of tarbush-mesquite-creosotebush.

10. "Some bushes," on the western portion and "few bushes" on the eastern portion. In areas nearby, the surveyors mentioned ardilla, sagebrush, and good grama grass. Tarbush was present in later years, so the western portion was considered some tarbush (category 5B) and the eastern portion was considered few tarbush (category 5A).

11. "Good growth of small bushes." Tarbush was present in later years, so this area was considered 5B.

12. "Few small bushes." This was interpreted to mean a few tarbush (5A) because it was found to be present in later years. Crucifixion thorn is present today in that area; but no mention was made of it.

13. "Grass good on east ½ mile, very little grass but abundance of bushes on west ½ mile," and "land undulating, poor and sandy, produces mesquite and a great variety of small bushes" were the phrases used to describe this area. Mesquite and fourwing saltbush were present in later years so this area was classified as abundant mesquite (category 1C).

The previous interpretations were made very conservatively so that areas which actually had one or more of the three brush species present would not possibly be overlooked.

1915 Survey. The Jornada Range Reserve was surveyed in 1915, using an ocular reconnaissance method. Common names were used in many instances on write-up sheets. In 1934, the 1915 write-up sheets were reviewed and the names and density figures were changed to the standards in use at that time. The density adjustments were made on the basis of quadrat records. The field write-up maps contained vegetation type numbers which were listed on field vegetation write-up maps. The vegetation write-ups were analyzed and categorized. The field vegetation maps were on a scale of 4 in. to the mile. They were reduced to 2 in. to the mile and transferred to a soils map overlay.

1928 Survey. The 1928 survey was conducted according to present-day standards for ocular reconnaissance surveys. In most cases, botanical names were used in the mapping. On the northeastern part of the range, observations were made from the section lines. On other portions of the range, each section was traversed a number of times depending on the complexity of the vegetation types and the productivity of the area. The original write-up maps were on a 2 in. to a mile basis. Therefore, the composite map was made by tracing on the type lines after categorizing the various vegetation types.

1963 Survey. On the portion of the Jornada included in this study but now under lease to White Sands Missile Range, very little grass is present. On that area the pace transect method was used to measure the canopy cover of the vegetation present. The observers checked themselves in the morning and thereafter made estimates of the composition unless a new type was encountered. When a different type of vegetation was encountered, pace transects were made to familiarize the observer with the canopy cover of the various species present in that type. Most of the section corners in the southeastern part of the study area were located, and all the section lines were checked. The section lines were followed with jeeps, and the odometer was used to check the extent of the various vegetation types. On the northern part of the area, only the east-west section lines were checked because most of the area is in mesquite sand dunes.

Another method was used on the portion of the Jornada presently being grazed. The grassland areas are sampled annually during the growing season by means of 100 ft line-intercepts (Canfield 1941). Data collected annually from approximately 1,100 observations were studied. In addition, the entire area presently grazed was surveyed by ocular reconnaissance in 1963 and the vegetation types were cate-

gorized. The vegetation map was then transferred to a soils map overlay on a 2 in. to the mile scale for analysis.

Vegetation map analysis. The 1858, 1915, 1928, and 1963 vegetation maps were planimetered by vegetation type on the two-inch to the mile scale map. The vegetation maps overlying the soil map were again planimetered by soil types within the vegetation types. The soils map shown in Figure 2, but on a 2 in. to the mile scale, was used to measure the acreage of each soil type. The acreage obtained when the soil types and vegetation types were measured independently was used to check against the acreage obtained when soil types were measured within vegetation types. Recalculations and adjustments were made where needed.

EXPERIMENTAL RESULTS

Vegetation Types

A planimeter was used to measure the area contained in the various vegetation types. The area of vegetation types for the four surveys is shown in Table 1 and Figures 6, 7, 8, and 9.

Area with no mesquite, tarbush, or creosotebush (0). The area with no mesquite, creosotebush, or tarbush has steadily declined throughout the study period. In 1858, there were 83,625 acres with none of the three brush species present. In 1963, the entire study area was mapped as having one or more of the brush species present, but on some small areas brush is practically non-existent. On the 1915 and 1928 vegetation analyses, a trace of brush was disregarded. Therefore, areas having a trace of brush present were mapped as brushfree.

Mesquite (1). The area covered by mesquite has increased from 29,089 acres in 1858 to 91,701 acres in

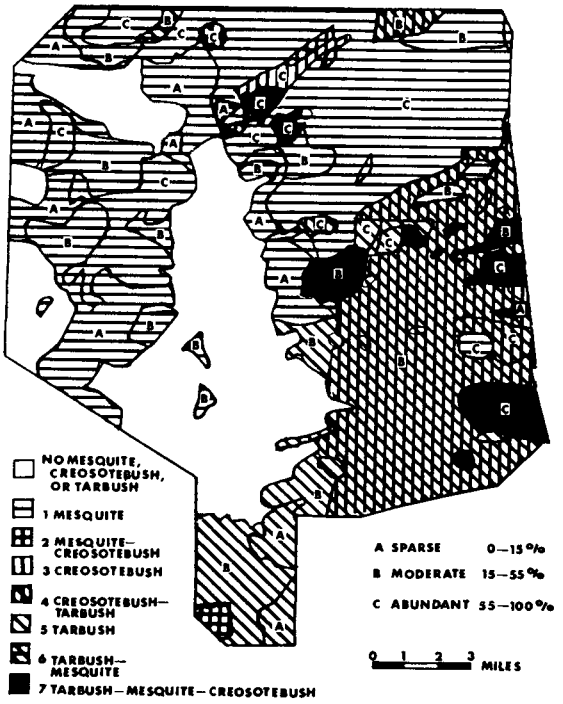

FIG. 7. Major brush species by species composition classes in 1915 on the Jornada Experimental Range.

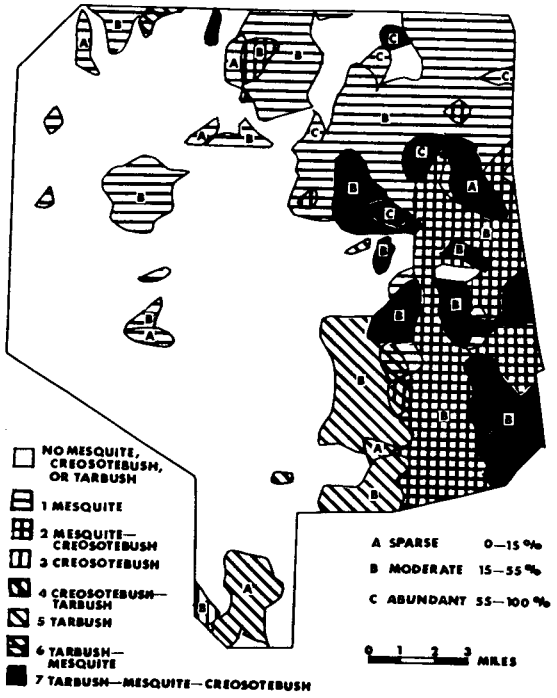

FIG. 6. Major brush species by species composition classes in 1858 on the Jornada Experimental Range.

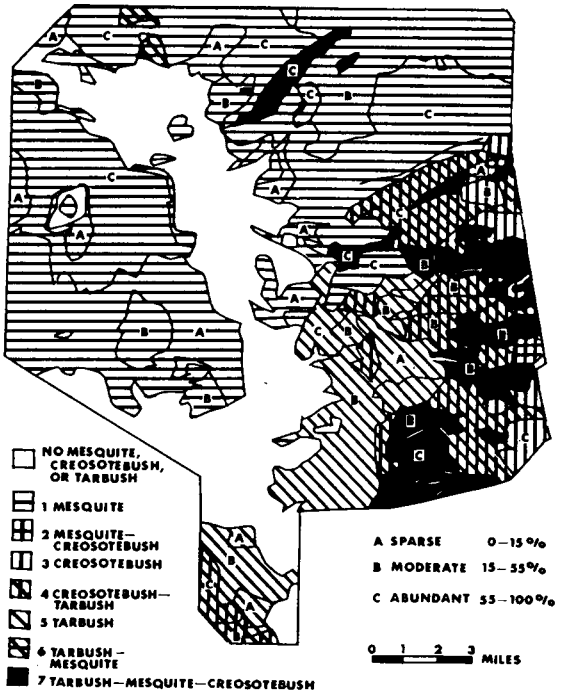

FIG. 8. Major brush species by species composition classes in 1928 on the Jornada Experimental Range.

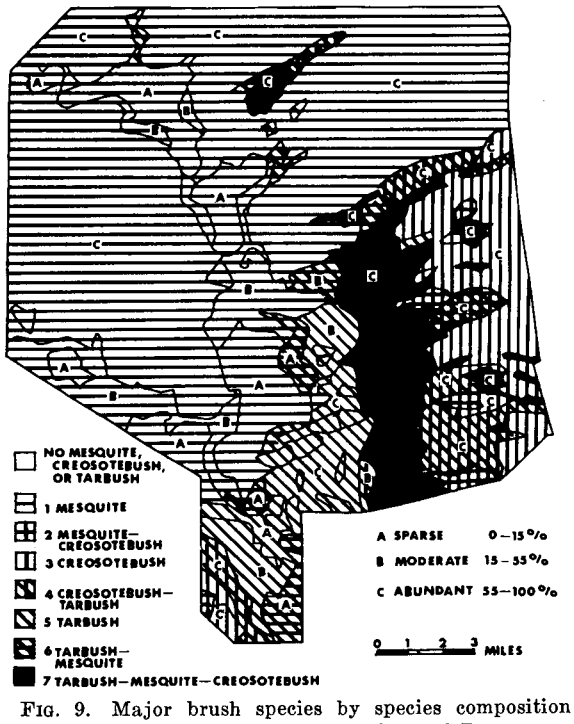

FIG. 9. Major brush species by species composition classes in 1963 on the Jornada Experimental Range.

1963 (Table 1). The greatest increases in mesquite invasion have occurred from 1858 to 1915 and from 1928 to 1963. The area in moderate mesquite was 22,074 acres in 1858. In 1915, it dropped to less than 11,000 acres. Most of that 22,074 acres changed to the abundant mesquite category (1C), as in 1915 over 32,000 acres were in that category.

The black grama type grassland is illustrated in Figure 10A. Figure 10B shows an area of low mesquite dunes which probably had as good a stand of grass only 75 yrs ago as that in Figure 10A. The dunes in Figure 10B appear to be relatively young. They are smaller than many of the older sand dunes.

Mesquite-creosotebush (2). There were over 9,200 acres of the mesquite-creosotebush type in 1858, but it has declined since that time. The sloping area on the southeastern portion of the study area contained most of that type. At that time there was a fairly good stand of grass present. From the notes made by the surveyors, it seems reasonable to assume that the grass stand was similar to that in Figure 11A, photographed in 1920, which was a mesquite-creosotebush-grass area that was part of the study area near the Dona Ana Rain Gauge (see Fig. 3). In 1915, two small areas of sparse mesquite-creosotebush (2A) were present near the Dona Ana Rain Gauge (see Fig. 6). They were bordered by abundant mesquite-creosotebush (2C). By 1963, the mesquite had decreased and the creosotebush had increased enough so that the mesquite was of little consequence. There seems to be no logical explanation for the disappearance of creosotebush from the mesquite-creosotebush areas located along the northern edge of the range in 1858 and 1915.

TABLE 1.—Acreage in major brush species by species composition classes for the years 1858, 1915, 1928, and 1963 on the Jornada Experimental Range.

Vegetation Type		Year			
		1858	1915	1928	1963
No mesquite, tarbush, or creosotebush (0)		83,625	35,459	32,833	
Mesquite (1)	A*	749	15,134	20,789	14,756
	B**	22,074	10,890	14,860	10,794
	C***	6,266	32,255	29,676	66,151
Mesquite-creosotebush (2)	A		126	309	
	B	9,235		379	65
	C		629		1,787
Creosotebush (3)	A				
	B	644		1,167	
	C		926	1,869	12,388
Creosotebush-tarbush (4)	A		367	1,583	
	B	251	27,069	3,307	1,168
	C		2,425	7,425	4,876
Tarbush (5)	A	2,707	3,200	4,315	2,748
	B	6,358	7,267	9,243	4,713
	C		717	1,383	4,387
Tarbush-mesquite (6)	A		41	410	2,364
	B	501	742	406	2,004
	C			1,012	1,727
Tarbush-mesquite-creosotebush (7)	A	571	428	724	175
	B	9,578	2,847	6,586	
	C	1,916	3,953	6,199	14,372
Total Acres		144,475	144,475	144,475	144,475

*"A" = 1 to 15% brush.
**"B" = 15 to 55% brush.
***"C" = 55 to 100% brush.

The large acreage in the southeastern part of the study area shown in 1858 (Fig. 6) as mesquite-creosotebush was later invaded by tarbush. Along with the tarbush invasion, creosotebush increased while the relative amount of mesquite decreased.

Creosotebush (3). The acreage covered by creosotebush had increased steadily from about a section in 1858 to over 12,300 acres in 1963. Most of this increase has come about since 1928.

The large area of creosotebush shown on the 1963 map contains remnants of old mesquite plants. Most of the mesquite plants appear to be very old. They are 3 to 5 ft high and usually have a trunk of about 3 to 5 in. in diameter. Some plants are dead and others are nearly dead. Remnants of dead tarbush plants are also present in creosotebush areas. Much of the area which is now creosotebush was previously

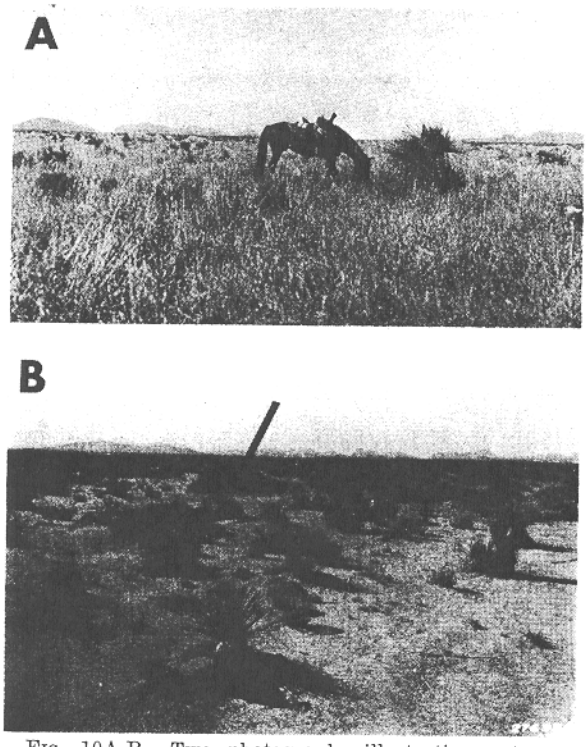

FIG. 10A-B. Two photographs illustrating extremes in conditions on a sandy soil on the Jornada Experimental Range. A. A good stand of black grama. B. Low mesquite dunes (note man standing behind the dune).

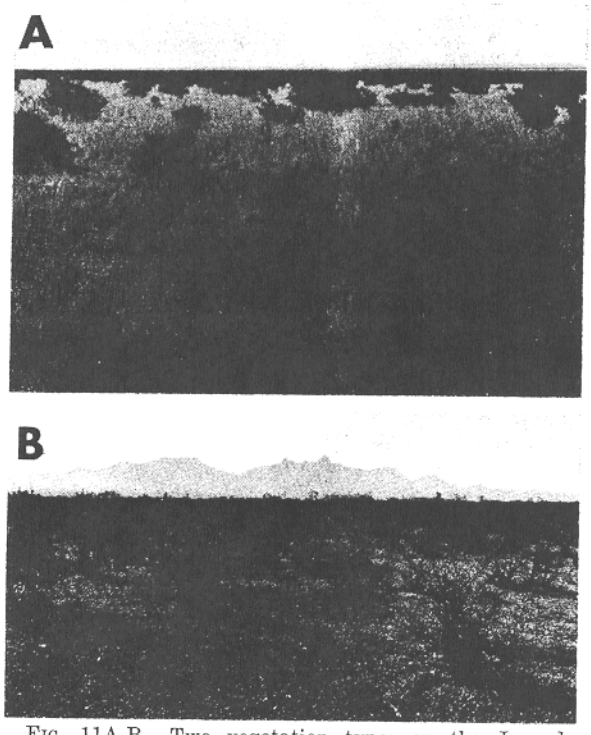

FIG. 11A-B. Two vegetation types on the Jornada Experimental Range. A. Mesquite-creosotebush-grass type. Taken in 1920 at Dona Ana Rain Gauge (see Fig. 3 for location). B. Typical tarbush-mesquite-creosotebush type.

mesquite-creosotebush, creosotebush-tarbush, and/or tarbush-mesquite-creosotebush type.

Creosotebush-tarbush (4). At first glance, the acreages shown for creosotebush-tarbush appear to be in error. In 1858, 251 acres were mapped, whereas in 1915 over 29,000 acres were mapped as creosotebush-tarbush. By 1928, it had decreased to about 12,000 acres. It is apparent from Figures 6, 7, and 8 that the southeastern part of the study area was mapped quite broadly in 1915. In 1928, just the opposite was true; it was mapped intensively. Much of the area in the southeastern portion of the study area which was shown to be creosotebush-tarbush in 1915 had mesquite present with the creosotebush and tarbush in both 1858 and 1928. In addition, there were a few spots which actually had no brush present in 1928.

The creosotebush-tarbush area actually decreased about 3,000 acres from 1915 to 1928 as a consequence of changing to the creosotebush type; this was due to the decrease in grass cover and an increase in creosotebush. The change from tarbush-creosotebush and tarbush-mesquite-creosotebush to creosotebush was over 9,000 acres during the 1928 to 1963 period.

Tarbush (5). The area which had tarbush unaccompanied by creosotebush or mesquite increased in acreage from 1858 to 1928. There was a larger area of tarbush in the southern end of the Jornada in 1915 (Fig. 7) than in 1928 (Fig. 8). This was evidently due to observer differences. A great increase of acreage in tarbush occurred farther north in the study area in 1928 which compensated for the decrease in measured acreage of tarbush on the southern end of the range.

The grass cover remained good in the tarbush stand until recent years. No great increase in acreage of abundant tarbush was recorded until the 1963 survey when over 4,000 acres were mapped. The total acreage in which tarbush was unaccompanied by mesquite and creosotebush actually decreased during the 1928 to 1963 period because much of the area was invaded by creosotebush and mesquite. The tarbush type in the southeastern part of the study area shifted to the west and was invaded by the creosotebush and mesquite from the east at a faster rate than the tarbush invaded the grassland to the west. In the southern end of the range, the creosotebush invaded the tarbush area from the higher elevations to the west.

Tarbush-mesquite (6). The tarbush-mesquite type increased in acreage from 1858 to 1963. The area dominated by tarbush-mesquite in the southeastern part of the study area has shifted westward as creosotebush has invaded from the higher elevation to the east. There are a few isolated areas in the sand dune type which have persisted for many years; however, they have become smaller in size. In most cases, the other tarbush-mesquite areas have been invaded by creosotebush. It appears that in a certain lowland area the tarbush moves into the mixed

TABLE 2.—Percent of area by soil types in major brush species, by species composition classes, for the years 1858, 1915, 1928, and 1963 on the Jornada Experimental Range.

Soil type	Acres in Soil Type	Percent of Study Area	Year	None	Mesquite			Mesquite-creosotebush			Creosotebush			Creosotebush-tarbush			Tarbush			Tarbush-mesquite			Creosotebush-tarbush-mesquite		
					1A*	1B**	1C***	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C
A	1,426	1.0%	1858	100.0																					
			1915	100.0																					
			1928	83.3	2.7	14.0																			
			1963		87.0	10.5	2.6																		
B	2,809	1.9	1858	97.6																					
			1915	66.7	27.4		2.2														2.3				
			1928	83.7	9.1		6.2														3.6				
			1963		85.0	7.1	1.5												0.3			0.7			
																						6.4			
C	1,742	1.2	1858	94.1	5.8																				
			1915	77.5	8.4	14.0																			
			1928	91.7	6.0	2.4																			
			1963		82.5	12.6	4.9																		
D	2,737	1.9	1858	95.4														4.5							
			1915	40.9													36.7	22.3							
			1928	73.5													0.7	25.6							
			1963		12.2												25.6		32.0	30.2					
E	26,090	18.0	1858	33.2		3.9			21.5						0.8		1.0	23.0			1.7			14.3	0.6
			1915	4.8	4.0	0.1	2.8						0.3	0.9	61.0	2.1	4.1	7.3	1.4	0.2	0.5		1.1	7.1	2.1
			1928	6.4	2.0	1.4	5.5		0.2			0.4	1.6	3.6	8.1	5.7	11.9	23.2	3.8	0.9	1.3	0.8	1.0	12.2	9.9
			1963			0.7	1.3			2.2			14.2		4.1	6.4	3.3	8.7	13.3	1.2	4.1	3.6	0.5		36.5
F	2,565	1.8	1858	49.8													50.3								
			1915	6.2													3.4	90.5							
			1928	28.6												2.8	21.1	45.2	2.3						
			1963													15.3	12.9	62.4		4.0	5.5				
G	1,345	0.9	1858	54.2													40.9							4.8	
			1915														31.4	68.5							
			1928	25.3												3.2	28.6	40.4					2.5		
			1963													1.1	2.8	58.0		34.4			3.6		
H	586	0.4	1858	93.8	6.1																				
			1915	4.3	95.7																				
			1928	87.0	10.4														2.6						
			1963		95.7	4.3																			
J	10,226	7.1	1858	2.1		1.0	54.5								0.4		0.2	2.0					4.3	35.5	
			1915		0.8		2.8						0.8		59.0	9.6	0.4						0.6	2.7	23.3
			1928	0.5					3.2			7.3	11.6	4.4	5.8	14.9	0.4	2.0		0.6			3.7	31.7	13.9
			1963				0.2		0.6	8.4			59.0		1.1	20.4					0.1	0.7			9.6
K	1,134	0.8	1858	64.3								6.1					29.6								
			1915	5.8				5.6										88.6							
			1928	6.5						4.3					8.9	46.8	12.6	22.1	3.1						
			1963										5.6			61.3	3.6								25.1

TABLE 2. continued.

Soil type	Acres in Soil Type	Percent of Study Area	Year	Mesquite				Mesquite-creosote-bush			Creosote-bush			Creosotebush-tarbush			Tarbush			Tarbush-mesquite			Creosotebush-tarbush-mesquite		
				None	1A*	1B**	1C***	2A	2B	2C	3A	3B	3C	4A	B4	4C	5A	5B	5C	6A	6B	6C	7A	7B	7C
L	1,302	0.9	1858	100.0																					
			1915	85.6	6.8	4.8	2.8																		
			1928	69.0	23.0	7.9																			
			1963		25.8	64.3	9.9																		
M	3,606	2.5	1858	99.1													0.8								
			1915	82.6	1.4												15.4	0.4							
			1928	94.6	1.2												0.6	0.9	2.6						
			1963		44.2	12.2											21.8	0.8	1.1	11.2	8.6				
N	493	0.3	1858						4.1			54.6					41.4								
			1915					12.8		63.9								23.3							
			1928												43.6	56.4									
			1963							18.9			81.0												
O	45,992	31.8	1858	86.9	1.0	10.6			0.8			0.6												0.2	
			1915	38.1	22.5	17.6	19.6									0.5		0.8			0.5		0.1	0.3	
			1928	27.6	32.0	9.0	28.6								0.5	0.2		0.5	0.4	0.2	0.1	1.0			
			1963		8.2	9.9	79.3											0.1		0.5	0.2	0.8			1.0
P	33,427	23.1	1858	28.3		48.3	2.1		9.6			0.1						0.1					0.4	6.2	5.2
			1915			6.9	65.7			0.9			2.3	0.4	15.0	2.0			1.0		0.8			1.7	3.1
			1928		5.0	29.2	44.0	0.9				0.9	0.7	0.4	0.2	10.0	0.1	0.3			0.1	0.9	0.2	0.5	6.6
			1963		0.9		81.3			0.7			6.4								1.0	0.6			9.4
R	1,822	1.3	1858	100.0																					
			1915	66.3	23.4	7.2	3.1																		
			1928	52.8	33.6	1.1	12.4																		
			1963		6.1	43.2	50.7																		
S	3,582	2.5	1858	100.0																					
			1915	79.3	20.6																				
			1928	76.3	22.6	1.0																			
			1963		54.5	39.1	6.3																		
T	3,058	2.1	1858	100.0																					
			1915	77.9	22.1																				
			1928	42.0	52.5	5.5																			
			1963		14.9	64.2	20.9																		
U	324	0.2	1858	89.5	10.5																				
			1915	40.1	59.9																				
			1928	100.0																					
			1963		88.2		11.7																		
V	209	0.1%	1858		66.5				33.6																
			1915			20.1	35.4								44.5										
			1928			36.4							17.2	21.0		20.1	5.3								
			1963				52.6						33.5								13.9				

*1 to 15% brush.
**15 to 55% brush.
***55 to 100% brush.

grass and burrograss-tobosa types, first, and then the mesquite invades the tarbush. In the southeastern part of the range, a broken band of mesquite-tarbush which has a fair stand of grass is an ecotone between an area of grassland which has a sparse stand of mesquite to the west and an area of tarbush-mesquite-creosotebush to the east.

Tarbush-mesquite-creosotebush (7). The 11,494 acres of moderate and abundant tarbush-mesquite-creosotebush shown for 1858 in the eastern part of the range (Fig. 6) may be excessive because of the conservative method used in classifying the areas of unidentified brush. Typical tarbush-mesquite-cresotebush type is shown in Figure 11B. The 1915 acreages may be too low, as was pointed out earlier, because that area was not mapped as intensively as in later surveys. It appears that in the southeastern part of the study area the area of mixed brush type is shifting westward to a lower elevation. Creosotebush seems to be able to increase itself at the expense of grass, mesquite, and tarbush.

VEGETATION CHANGES BY SOIL TYPE

It is difficult to generalize about vegetation changes on any grouping of soil types. Table 2 shows the percent of each soil type occupied by the various vegetation types. Vegetation data by percent species composition are presented for each of the 4 yrs in which the study area was surveyed. The results shown in Table 2 indicate that each soil must be discussed as a separate entity.

Soil type "A," a calcareous clay with gypsum crystals throughout the profile, has been only slightly invaded by mesquite. In 1963, 87% of the area had a very sparse stand of mesquite. Grass is also wanting on a large portion of that area. Only about 3% of the area in this soil type has regressed to the abundant mesquite type. This invasion has occurred primarily along the edge of this soil type where the clay has been covered by wind-blown sand.

The "B" soil, a calcareous loam with gypsum crystals present throughout the profile, generally occurs in close proximity to soil type "A." There has been a slight invasion of tarbush and mesquite on this soil type. Here again, as in the case of the "A" soil, 85% of the area has very little mesquite. In reality, only about 17% of the type has brush of any consequence. Some of the area which had abundant mesquite in 1928 shifted to abundant tarbush-mesquite in 1963, indicating that tarbush may be invading on this soil type.

Soil type "C" is a complex of calcareous-gypsiferous soils and has been invaded by mesquite to some extent. Since about 1928 about 5% of the area has shifted to abundant mesquite. Another 13% of the area has been invaded by a moderate stand of mesquite. Only occasional mesquite plants are present on much of the 82% of the area which is classified as sparse mesquite.

Soil type "D," a calcareous silt loam, has been invaded by tarbush to some extent. About 26% of the area in this soil type had a moderate stand of tarbush by 1928. In 1963 it had an abundant stand of tarbush on 32% of the area. The remaining 68% of the area had a sparse stand of mesquite and tarbush confined mainly to roadsides and other disturbed areas. There are sizeable areas of burrograss where crucifixion thorn in scattered stands is the primary shrub.

Soil type "E," a loam with inclusions of sandy ridges, makes up 18% of the study area. It is difficult to draw conclusions on this soil type as the data are affected to a great extent by the intensity of mapping used in the 1915 and 1928 surveys. In 1858, 67% of the area had brush present. Abundant and moderate brush were present on 98% of the area in 1963. The acreage of abundant mesquite has decreased from 1928 to 1963. All other abundant brush categories have increased. The greatest increase has come in categories where creosotebush is present. In 1963, 14% of the area had nearly a pure stand of creosotebush. The tarbush type was the only one which had an appreciable amount of grass in association with the brush in 1963.

The "F" soil type, a loam, had a sparse stand of tarbush on 50% of its area in 1858, and by 1928, 2% of the area in this soil type had an abundant stand of tarbush and 45% of the area had a moderate stand of tarbush while an additional 21% had a light stand of tarbush. Abundant creosotebush covered 3% of the area in 1928. There was an increase in the invasion by creosotebush between 1928 and 1963. The creosotebush invaded only the area previously having a presence of tarbush, the latter area being the only area in this soil type which had an abundant stand of brush in 1963.

A dense stand of tobosa is present on 42% of the area of the "G" soil, a deep, non-calcareous silt loam. The other 58% of the area has a moderate stand of tarbush. Tarbush has increased somewhat since 1858; however, this has been slow and the main change is the loss of grass cover on areas where tarbush has been present in a light stand for many years.

The "H" soils, shallow, eroded gyplands, have not been invaded by brush to any extent. The values shown in Table 2 vary greatly. However, it is the case of so few mesquite being present that, on about 90% of the area, they were disregarded in the 1928 survey. The 2.6% of the area shown to have a heavy stand of tarbush was obviously a mapping error since no tarbush was recorded in this soil type at other times.

The "J" soil, calcareous, shallow to moderately deep, gravelly, sandy loam, makes up about 7% of the study area. Nearly all of the area in this soil type is within the portion of the range under lease to White Sands Missile Range; therefore, most of the area in this soil type has not been grazed since 1953. Practically the entire area in this soil type had brush present on it in 1858. Nearly 55% had a poor stand of grass and an abundant stand of mesquite. Creosotebush, tarbush, and mesquite were present in a

moderate stand on another 36% of the area. By 1928, 12% of the area supported an abundant stand of creosotebush, and by 1963 this had increased to 59% of the soil type. The area covered by abundant tarbush and creosotebush increased to 20% by 1963. The increase in acreage of abundant creosotebush and creosotebush-tarbush has been at the expense of the mesquite and grass which was growing in association with it in 1858. The area occupied by the three brush species growing in association with one another decreased from about 45% in 1928 to less than 10% in 1963.

The "K" soil type is a moderately deep to deep, gravelly, sandy loam. The 1858 survey showed that 64% of the area in this soil type was free of tarbush, mesquite, and creosotebush. About 30% of the area had a sparse stand of tarbush. By 1915, 89% of the area had a moderate cover of tarbush. Between 1915 and 1928 some creosotebush invaded the area where tarbush had been growing in association with some grass. The grass cover decreased as the creosotebush increased. Less than 7% of the area was free of brush in 1928; however, 40% had a fair cover of grass. By 1963, the total area had abundant brush and very little grass, primarily fluffgrass, remained. In 1963, 6% of the area had abundant creosotebush, while creosotebush in conjunction with tarbush covered 61% of the area and creosotebush-tarbush-mesquite covered about 25% of the acreage. The creosotebush invasion appears to be slower on the "K" soils than on the "J" soils. The main difference between the soils is the depth.

There was no brush present in 1858 on the "L" soil, a sandy loam with a gypsum subsoil. Mesquite is the only brush which has invaded this soil and that has occurred only recently. Between 1915 and 1928 about 25% of the area became invaded with a sparse stand of mesquite. The area which had no mesquite continued to diminish and by 1963 26% of the area had sparse mesquite, with more dense stands being present on the remainder of the area.

The "M" soil, a moderately deep to deep, calcareous, sandy loam, has a slight amount of mesquite invasion. By 1963, 12% of the area had been invaded to the extent of having a moderate stand of mesquite. More area was mapped as having tarbush present in 1915 than in 1928; however, in 1928, 3% of the area had abundant tarbush. In 1963 about 23% of the area had a moderate or abundant stand of mesquite and/or tarbush.

The "N" soil, a shallow to moderately deep, gravelly, sandy loam, makes up less than 1% of the study area. Brush has been present on this soil type since before 1858; however, a good stand of grass was also present. By 1915, over 87% of the area was covered with a moderate or abundant stand of brush. In 1928 and 1963, creosotebush was prevalent throughout the soil type. The data indicate an absence of mesquite in 1928; however, mesquite probably was present in small amounts but was disregarded by the 1928 examiners. It seems unlikely that mesquite increased in percent composition from 1928 to 1963. Tarbush decreased as creosotebush increased.

The "O" soils, loamy fine sands occurring in the basinal portion of the study area, make up 32% of the study area. Being such a large area, the soil is not as uniform as some of the smaller areas. However, none of the surveys indicates more than 3% of the area as having tarbush and/or creosotebush present. Invasion by mesquite was rapid; 20% of the area had abundant mesquite in 1915, about 29% of the area had abundant mesquite in 1928, and 79% of the area had abundant mesquite in 1963. Only 8% of the area had a sparse stand of mesquite in 1963.

The "P" soils are loamy fine sands of piedmont origin and cover about 23% of the study area. The 1858 survey indicated that about 28% of this area was free of mesquite, creosotebush, and tarbush. By 1915, the entire area had been invaded by brush. It appears that the area was first invaded by mesquite. In 1858, 48% of the area had a moderate stand of mesquite and creosotebush was in moderate proportions on about 10% of the area. By 1928, the area of mesquite which was moderate in 1858 had become abundant and the area which was free of brush had become a moderate stand of mesquite. By 1963, the area of creosotebush had increased to about 6%. This was mainly at the expense of tarbush, as the tarbush-creosotebush type decreased; however, in association with mesquite, the latter two are present on 11% of the area. Nearly the entire area covered by this soil type is in sand dunes with the main vegetation being mesquite; however, an increase in creosotebush was noted. As was stated in describing the "P" soils, much early Indian activity has taken place on this area.

There was no brush present in 1858 (Table 2) on "R" soil, a deep, loose, loamy fine sand. Since then it has been invaded by mesquite. By 1963, 51% of the area had abundant mesquite and another 43% had a moderate amount.

The "S" soil type is a loamy fine sand. This soil type has some of the best black grama stands on the Jornada Experimental Range. Most of the mesquite invasion on this site has taken place since 1928. This soil has the smallest amount of mesquite of any of the sandy soils on the study area. About 40% of the area classified in 1963 as having a moderate mesquite cover actually has a low number of mesquite plants per acre, but grass is very sparse also.

The "T" soil type is a shallow to very shallow, gravelly loamy fine sand. This soil supports a good stand of black grama in some places. In 1858 there was no brush present on this soil. By 1928, 52% of the area had a sparse stand of mesquite and an additional 6% had a moderate stand. By 1963, 21% of the area had abundant mesquite and an additional 64% had a moderate amount.

The "U" soil type is a troublesome one to map

using the categories that have been established. It presently is unstable sand dunes over gypsum beds with the main cover being broom dalea. A sparse mesquite cover was present on part of the area in 1858 and 1915. However, the mesquite was so sparse that, in 1928, the surveyors mapped the entire area as free of mesquite, creosotebush, and tarbush. Since there were some mesquite present in 1963, 88.3% of the area was placed in the sparse category and 11.7% in the abundant category. The "U" soils cover only about 0.2% of the study area.

The area of rock outcrops ("V" soils) is less than 0.1% of the study area and has usually been mapped in with the surrounding vegetation so the information on this site is meager. However, the data indicate that mesquite and creosotebush have invaded this site to a much greater extent than tarbush.

MISCELLANEOUS OBSERVATIONS FROM THE 1858 SURVEY

There were some items of interest in the 1858 survey which do not have a direct bearing on the vegetation analysis. However, they may be important for a better appreciation of the vast changes that have occurred. The surveyors, in reference to the water from Goldenburg Spring at a point about two miles below the spring where the Ranch was located in later years, wrote, "A stream of water about 100 links south of this corner runs S of W between sections 2 and 35.—wide, bold stream, strong current." At the present time this spring runs only intermittently at its source. The surveyors also mentioned that Ropes Spring draw was dry at a point some 2 mi below the spring but that it was flowing about 1 mi below the spring. It was flowing more heavily at that time than it is at present. Both of these observations were made in the spring of 1858, normally a dry time of the year.

Prairie dogs were prevalent on the Jornada plain. The surveyors mentioned prairie dogs or the grass being closely grazed by prairie dogs at four places. Two locations were cited on heavy gypsiferous clay soil and two others on sandy areas.

Cactus entrana or cactus was mentioned as abundant on six section lines located on "P" soils near the northern boundary which had good grass and some brush in 1858. None is present now and the area is dominated by mesquite sand dunes. The local Spanish-Americans call the cholla-type cactus "entrana."

On extensive areas of grassland, "Palmia" and "Palmilla" were mentioned. Wooton & Standley (1915) listed Palmilla as the common name for *Yucca elata* Engelm. The surveyors also mentioned a winter grass in one small area which was assumed to be *Aristida* spp.

"Sedgebush" was a term commonly used by the surveyors in describing the vegetation. The authors can find no reference to sedgebush in any printed material; however, it is logical to assume that they meant Ephedra spp. Ephedra has a sedgelike appearance.

The surveyors used the term "chamiza" quite frequently in describing the vegetation. Chamiza is often used in the Southwest as a general term when referring to bushes. Wooton & Standley (1915) listed chamiza and sagebrush as common names for *Atriplex canescens*. They also stated that many of the newer immigrants referred to any bush having a gray color as sagebrush. The surveyors used the term "sagebrush" in some instances; however, it is possible that when speaking of sagebrush they were referring to *Artemisia filifolia*, which is present on the study area. It is possible that *Lycium* spp. may also have been included in the shrubs the surveyors called "chamiza."

When the surveyors finished with a township, they wrote up a general description of its features and vegetation. In speaking of a township located east of Taylor Well (Fig. 1), they said that during the growing season the farmers in the valley sent their livestock to that area to keep them from disturbing their crops and also to fatten on the "luscious grass." In 1963, there was hardly any grass in that township except one small area of tobosa and burrograss.

In speaking of the township south of South Well, they said: "The soil of this township is average good 2nd rate and it is believed that much of it could be brought into cultivation produce good cereals its principal value consists in its rich pasturage which is sufficient to raise immense herds of stock."

In writing of the area on the western part of the study area, the surveyors mentioned talk of diverting a portion of the Rio Grande to the Jornada, thereby making that area desirable for farming and stock raising. This was proposed to the United States Government in 1888 (Bowman 1888). The surveyors mentioned that the following townships were adapted to the culture of grain crops: north of Summerford Well, the township east and north of Jornada Headquarters, and the townships north of Red Lake Well.

DISCUSSION AND CONCLUSIONS

BRUSH DISTRIBUTION IN RELATION TO SOILS

All of the soil types on the study area have had mesquite present on them at some time. Some of the soils have not had tarbush growing on them to any extent, but tarbush has been present on some soils that have not had creosotebush.

General vegetation changes by soil types are shown in Table 3. No creosotebush and very little tarbush invasion has taken place on the soils having gypsum in the profile. Only a light mesquite invasion has occurred and that is mainly on areas where windblown sand was deposited over the gypsiferous soil. The latter statement is in accordance with Campbell & Campbell (1938) who stated that when sand was blown over the gypsum soils of the Jornada plain, the vegetation took on an appearance of typical Prosopis sand dunes. Waterfall (1946) stated that creosotebush was unable to live on gypsiferous soil. He reported an absence of mesquite, tarbush, or creo-

TABLE 3.—General changes in vegetation type by soil type.

Percent of Study Area	Soil Type	Change
4.7	A,B,C,H,U (affected by gypsum)	None→slight mesquite invasion
38.6	L,O,R,S,T (loamy sands and sandy loams)	None→moderate mesquite
2.5	M (sandy loam)	None→tarbush-mesquite
1.9	D (calcareous silt loam)	None →tarbush→tarbush*-mesquite
0.9	G (non-calcareous silt loam)	Tarbush→tarbush*-mesquite
1.8	F (loam from igneous rock)	Tarbush→tarbush*-creosotebush
0.8	K (gravelly sandy loam)	Tarbush→mesquite-tarbush*-creosotebush*
0.3	N (shallow to moderately deep sandy loam)	Tarbush and creosotebush**→creosotebush
23.1	P (aeolian loamy fine sand piedmont deposits)	Mesquite→mesquite*-creosotebush
7.1	J (shallow calcareous sandy loam over limestone)	Mesquite→creosotebush-tarbush→creosotebush*
18.0	E (complex of deep loamy soils and sandy ridges)	Mesquite-creosotebush and tarbush**→creosotebush-tarbush

*Indicates dominant species.
**Indicates two plant communities.

sotebush on the gypsiferous soils of southwest Texas and adjacent New Mexico. The findings of this study differ from those by Waterfall (1946) in that mesquite and a small amount of tarbush were found on gypsiferous soils.

Moderate mesquite invasion has occurred on the "L," "O," "R," "S" and "T" soils which are loamy sands and sandy loams. Tarbush and mesquite have invaded to a moderate extent on soil "M," which is a sandy loam. Tarbush has become the dominant vegetation on the "D" soils, which are calcareous silt loams; some mesquite is also present.

The "G" soils, non-calcareous silt loams, had some tarbush in 1858; since then, tarbush has become the dominant plant with a lesser amount of mesquite being present. "F" soil, a loam derived from igneous rock, had some tarbush present in 1858; since then, it has become dominant and creosotebush is invading the tarbush.

Tarbush was present in 1858 on the "K" soil, a gravelly sandy loam, but grass was good. Later, tarbush became the dominant plant with some mesquite present. By 1928, creosotebush had increased, and in 1963 it dominated the site.

The "N" soil, a shallow to moderately deep, sandy loam, had tarbush on part of the area and creosotebush on part of the area in 1858. Since then, creosotebush has become the dominant plant on this soil type. The soils making up the "D" category had mesquite present in 1858 and have been invaded to some extent by creosotebush; however, mesquite is still the dominant plant.

The "E" soils, a complex of deep loams with sandy ridges, had mesquite in one area in 1858; on another part of the area creosotebush and tarbush were present. Since then, creosotebush and tarbush have invaded the entire area.

The "J" soil is a shallow, calcareous soil over limestone. Mesquite was present on this area in 1858; by 1915 creosotebush and tarbush had invaded, and in 1963 creosotebush dominated on this soil. Fosberg (1940) stated that *Larrea divaricata* grew best on limestone-derived alluvial fans. In this study, no comparison was made to see on which soil type creosotebush was best adapted, but the soils underlain by limestone had a higher percentage of their area covered by creosotebush than any of the other soils in the study area.

In Arizona, Shreve & Mallery (1933) found that the depth of soil could be determined by observing the density and height of creosotebush. In this study, no differences were observed in height and density of creosotebush between the "N" soil and the "J" soil; however, the bushes were larger and more dense on the deeper parts of the "J" soil than on the shallow areas of the "J" soil.

Anderson (1956), using potted soils from six New Mexico sites varying in soil texture from rocky silt loam to heavy clay loam and with vegetation type varying from creosotebush to good tobosa and good black grama, found that creosotebush was equally adapted to each of the six soils tested. None of the soils he studied was gypsiferous. The findings of this study agree with Anderson (1956) since creosotebush was present on all soil textures.

Lesueur (as cited by Cabrera, 1955) stated that on deep well-drained soils in the Chihuahuan district Flourensia predominates even to the point of crowding out Larrea. Muller (1940) failed to find any evidence to indicate that Flourensia dominated or was weakening the stand of Larrea on heavy clay beds overlain by cobble and sandy soil in Brewster County, Texas. Lesueur's statement (cited by Cabrera, 1955) is definitely in disagreement with the findings of this study and also with Muller (1940) and Gardner (1951). Gardner (1951) stated that creosotebush was invading tarbush areas. The young creosotebush plants were found growing in the edge of tarbush areas, but there were no young tarbush plants growing in creosotebush areas. The general observations in this study follow the pattern described by Gardner (1951). It was also noted that young tarbush and creosotebush plants were found on some Prosopis sand dunes. Young mesquite plants were never found in creosotebush areas.

Creosotebush plants were not found on gypsiferous

soils on the study area; however, this does not mean that they cannot grow there. Creosotebush is known to occur on some gypsiferous sites in other areas. The most probable reason is that the seed has not been introduced to the area having gypsiferous soils on the study area.

The area dominated by creosotebush has increased in size from about a section in 1858 to over 12,000 acres in 1963. Creosotebush occurs primarily on relatively shallow, coarser textured soils on slopes. Mesquite-dominated areas, which are mainly on sandy soils, have increased in size from 6,200 acres in 1858 to over 66,000 acres in 1963, with more than half of this increase occurring since 1928. The area dominated by tarbush has also increased since 1928; however, much of the tarbush-dominated area has been invaded by creosotebush since 1928.

DISCUSSION OF FACTORS RESPONSIBLE FOR VEGETATION CHANGES

Various ecologists have attempted to classify the Jornada plain on the basis of their concept of the climax vegetation. Shreve (1917) considered the Jornada plain a transitional area between desert shrub and grassland. Clements (1934) classified it as desert plains grasslands. Brown (1950) did not recognize desert grasslands climax but said that it was maintained as grass due to some other factor. Humphrey (1958) reported that desert grasslands is not true climax but was kept free of brush in early days by recurrent fires. He listed five factors which were responsible for the increase in brush: 1. Changes in climate, 2. Grazing by domestic livestock, 3. Effect of rodents, 4. Suppression of grassland fires, 5. Competition.

Climatic changes. Weaver & Clements (1938) stated that creosotebush was a desert shrub left stranded on the desert plains grassland by the last dry phase of the climate. Gardner (1951) pointed out that the climate was not changing to conditions more suitable for brush. He concluded that the Jornada plain was once grass except for limited areas. The limited areas he mentioned are probably the droughty sites Weaver & Clements (1938) termed preclimax. Paulsen (1956), in a study of the rainfall records of the Jornada Experimental Range, noted no general climatic change but found apparent groupings of dry years and wet years. These groupings of dry and wet years have alternated at approximately 20-year intervals. Friedman (1957), in a statistical review of south and southwest Texas stations, concluded that rainfall occurs at random and that the fact that the rainfall is abnormally deficient in one year does not necessarily mean that rainfall of the next year will also be deficient.

According to Russell (1941), we are living in the latter part of an ice age, a period of crustial and climatic violence as great as any the earth has known. About 400 B.C. a period of maximum precipitation occurred in North America. True deserts were more limited in extent than they are now. The fifth century A.D. was dry and many lakes in the western United States appear to have dried out completely. It remained relatively dry until about 800 A.D. Warm, dry conditions returned in the tenth and eleventh centuries. There are indications that the Pueblo Indians present on the northeastern part of the study area left during a dry period, about 1276 to 1299 (Martin *et al.* 1956). Russell (1941) also stated that the fourteenth century was a period of great storminess and wet weather. It was during that time (1325) that the Aztec Indians settled Mexico. He further reported that the summer temperatures are warmer now than they were in the eighteenth century.

Great weather fluctuations have been present in the Southwest for centuries. The constant, very slow warming trend of the climate is causing the decrease in the size of the polar ice caps. It is causing the Great Salt Lake of Utah to become smaller each year. Should it not also have an effect on the size of the deserts? This slow warming effect, coupled with grazing, could have some effect on the vegetation of the Jornada plain. Since the climate of the Jornada is that of the drier part of the grasslands climate, only a minor change could have a great effect on the vegetation.

Grazing by domestic livestock. The effect of grazing by domestic livestock was believed to be of great importance in early studies on the Jornada. Jardine & Forsling (1922) stated that the end result of the overgrazing of black grama range was mesquite sand dunes. Campbell (1929), in studying the Prosopis sand dunes, indicated that by proper grazing management mesquite dunes could be returned to black grama grass. He did state that it could not be done during drought years. In 1931, a 640-acre enclosure was built on the Jornada Experimental Range. The enclosure was across a transitional area of black grama grassland and mesquite sand dune type. No livestock have grazed inside that enclosure since it was established. The mesquite sand dunes have advanced completely across the enclosure and out onto what was grassland in adjoining areas. Nelson (1934), in a study of the effects of drought and grazing on black grama, concluded that range which was conservatively grazed would recover from drought as rapidly as range which was not grazed. The density of conservatively grazed plots exceeded the density of ungrazed plots for several years of his study. He stated that conservatively grazed black grama formed more but smaller clumps which were better able to make use of limited moisture.

He concluded that heavy grazing year after year

(1) will decrease the density of black grama and eventually kill it.
(2) weakens the plants so that they cannot quickly recover following drought.
(3) permits inferior plants to become established.
(4) causes unstable soil conditions and trampling effects to develop.

(5) intensifies drought influences.
(6) reduces forage production.

Parker & Martin (1952) stated that once mesquite becomes established on the range, there is little that will kill it. Unpublished quadrat material from the Jornada files shows that on quadrat A-2 two mesquite plants were present when the quadrat was established in 1915. They remained very small for many years. During a drought one of them died. The drought lessened the grass competition and in recent years the mesquite plant that remained alive increased in size. It still covers only about a square meter. Quadrat A-2 is located in an area where there still are remnants of black grama.

Livestock are responsible for the dissemination of mesquite seed since the seed is capable of passing through their digestive tracts without being damaged. This, however, does not hold true for creosotebush since livestock have never been observed eating creosotebush. Occasionally on a frosty morning cattle have been observed eating the flowers and fruits of tarbush. Wright (1960) concluded that the effect of livestock as a means of disseminating mesquite seed was more a factor in mesquite invasion than the effect of their grazing. As was pointed out earlier in this study, domestic livestock may have used this area prior to the 1880's, but such use would have been only seasonal or intermittent due to lack of water. During the 1880's, the number of cattle increased and ranches became established. During this time the Detroit Troughs were put in. Heavy use of available forage probably occurred in the vicinity of the troughs. Other than for seasonal use, it is questionable that areas removed from water by any distance were heavily used. After the first wells were drilled, there is little doubt that the ranges were heavily stocked. By today's standards they were quite heavily stocked until the 1920's when the concepts of proper use were developed.

Effects of rodents. Rodents and rabbits consume a large amount of range forage. Much of this forage would be of value for livestock production. Rodents and rabbits are important in dissemination of seed also. Most investigators agree that rodents are more often a result of range deterioration rather than a primary cause of it. Norris (1950) reported that studies on jackrabbits, kangaroo rats, wood rats, and other rodents all indicate that these animals increase as overgrazing progresses.

Although rodents are of small consequence in relatively undisturbed grassland, they cannot be dismissed as having no importance. Wright (1960) stated that rodents should be considered only an aggravation of the problem rather than a primary cause.

Suppression of grassland fires. In the extensive reviews of literature regarding the Jornada del Muerto by Branscomb (1956), Wright (1960), and these authors, no record of extensive fires has been found. There appear to be no "word-of-mouth" reports of fires on the Jornada. Even though no record of fires on the Jornada plain was found, Branscomb (1956) concluded that fires did periodically sweep the area and were important in restricting the growth and development of shrubs. Wright (1960) stated that fires were not a factor in keeping the Jornada plain free of brush because there were no fires. He stated that the grass cover was not as great on the Jornada as it was in Arizona where most of the research with fire has been conducted. He doubted that the cover on the Jornada was sufficient to carry a fire.

Griffiths (1904*b*), referring to Arizona ranges, wrote: "It is interesting to compare this distribution with similar situations in the Mesilla Valley of New Mexico, where Professor Wooton states that *Bouteloua eriopoda* which is never an exclusive crop in southern Arizona, is often cut for hay." Wooton (1916), stated that 1,110 pounds per acre was the normal production for the Santa Rita Experimental Range. Paulsen & Ares (1962) reported a 15-year average herbage yield of 522 pounds per acre on good black grama range. It may be well to point out that the Arizona studies have been carried out under higher rainfall conditions than those of the Jornada plain. The Jornada Experimental Range is in the drier part of the semidesert grassland area, whereas portions of the Santa Rita Experimental Range which are sometimes compared with the Jornada are in a more mesic part of the semidesert grassland.

A dense cover of black grama may be capable of carrying a fire, provided there is sufficient wind. If fires did periodically sweep across the Jornada plain, it is difficult to believe that the early travelers on the Camino Real would not have mentioned this fact. Extensive records of the last 50 yrs also fail to mention any large fires. It is questionable what effect a fire on the Jornada plain would have on the mesquite. The fire needs to be hot to kill mesquite. In studies by Glendening & Paulsen (1955), in a controlled burn supplemented with 750 pounds of baled hay per acre, a significant number of mesquite seedlings were killed. However, only a few larger plants were killed. Reynolds & Bohning (1956) found that black grama was seriously damaged by fire. Humphrey (1962) concluded that fires need to be periodic to keep brush under control. He cited numerous situations where early travelers and researchers have claimed that the brush invasion was due to the absence of fire. There seldom is good grass cover around the base of a mesquite or creosotebush plant. Substantial vegetation around the base of a shrub is necessary to provide fuel for a fire which is hot enough to damage the shrub.

When C. T. Turney came to the Jornada plain, he brought with him the idea that burning of tobosa areas would provide better grazing. According to Bill McCall, the tobosa was killed where Turney

burned the swales.[4] This was also demonstrated by a fire which occurred in the early 1940's on a tobosa area on the southern end of the Jornada Experimental Range.[5] To this day, no tobosa has been present there. It is completely bare except for a few annual weeds. However, the value of fire in maintaining a mesquite-free semidesert grassland is questionable since black grama is susceptible to fire damage and mesquite is relatively resistant.

According to K. A. Valentine, a tobosa swale about 4 mi south of the Jornada Experimental Range was burned during a winter in the late 1930's. No permanent, detrimental effects resulted on that tobosa site, as an excellent stand is present today. The effects of fire on tobosa grassland are not well understood. Certainly tobosa is capable of carrying a hot fire, and it is very surprising that there are no greater occurrences of fire on the tobosa type.

Plant competition. Plant competition for space and moisture may have been a factor in keeping the shrub invasion rate at a minimum under pristine conditions. Even in undisturbed grass stands there are open areas where shrubs may at least germinate and make some initial growth when moisture conditions are favorable. If plant competition was a factor, any selective grazing by livestock or rodents would weaken the grass and favor the shrubs. Bare areas are present around the bases of mesquite and creosotebush plants. As the shrubs increase in size, the bare areas around the shrubs also increase in size. These bare areas are due to competition for moisture, rodent and rabbit activity, and a limited amount of livestock trampling.

ANALYSIS OF FACTORS RESPONSIBLE FOR VEGETATION CHANGES

In 1858 the Jornada Experimental Range was a great expanse of grass with only isolated spots of mesquite. On the higher areas along the mountains, brush was present; however, grass was also good in most places. A few tarbush plants were present in some of the lower lying areas. Since 1858 the grass cover has decreased tremendously, and the brush has increased to the point that it was present on the entire study area in 1963. Less than 25% of the study area had a fair stand of grass in 1963.

The western part of the study area had only a few isolated mesquite areas in 1858. Since that time these areas have increased in size and now mesquite is present on the entire western part of the study area. Vast areas having sandy soil are now dominated by mesquite sand dunes.

The mesquite areas on the western part of the study area were not located near places where any livestock water was present, either temporary or permanent, so it cannot be said that the mesquite was due to overgrazing. It is the opinion of some that since these areas are on somewhat higher ground than adjacent areas, there may have been some seed dispersal by wild horses. Horses tend to graze on high ground, so if they were present they might have been a factor. The early spread of mesquite was from the areas noted in 1858. Only in recent years have the areas around water been invaded.

On the northeastern part of the study area, Indian activity may have contributed much to the sand dune condition that exists there today. The presence of the ruins of an Indian pueblo on this area indicates that some farming may have taken place as the Pueblo Indians were farmers. Nomadic Indians made periodic hunting trips to that area long after the pueblo was abandoned. Since the Indians probably carried mesquite beans for food, they may have been a factor in seed dispersal.

The northeastern part of the study area was grazed intensively by domestic livestock before the lower elevations to the west were grazed. Photographs taken in 1912 by E. O. Wooton indicate that the sand dunes on the northeastern part of the study area looked in 1912 much as they do today.

South of the sand dune area on the eastern part of the study area is an area which had creosotebush present in 1858. A good stand of grass was also present. Some factor which is present now must have been absent prior to 1858 when the creosotebush and grass were in equilibrium on that area. Some early grazing took place on that area, but water was scarce so it probably was not heavily grazed.

The selective grazing of the grasses would tend to weaken them and allow more room for the competitive shrubs. Trampling also may have been a factor in starting deterioration. There would not have been heavy enough grass cover on those shallow soils to support fire, which would have had an effect on the creosotebush. The decrease in grass cover, aggravated by grazing, allowed more soil to become exposed to the elements of weather. When the soil on top of the ridges started eroding and washed down the slopes, it probably collected in the grass that was present at a lower elevation. Black grama plants are easily damaged by the depositing on, or the eroding of, soil. Once the vegetation cover has been depleted except for desert shrubs, there is little soil protection, and erosion by wind and water is great. An erosion pavement is formed and the topsoil that supported black grama erodes away. Protection from grazing at this point is useless because the site has deteriorated so that it cannot support a good stand of grass; no changes are present on the area which has not been grazed for 10 yrs. However, it should be noted that competition from the brush is the main reason no changes have taken place with protection from livestock. If brush is removed, a sparse stand of grass may develop. On the southeastern part of the study area, it appears that mesquite was present in a scattered stand;

[4] Interview with Bill McCall, December 26, 1963.

[5] Personal communication from K. A. Valentine, Associate Professor of Animal Husbandry, New Mexico State University, University Park, N. M., on January 15, 1964.

then creosotebush and tarbush invaded as the grass declined in percent composition, and presently the tarbush, mesquite, and grass declined in composition while creosotebush has increased greatly.

On the heavier soils on the central and southern parts of the study area, tarbush was present in 1858 in limited areas. Those were mainly on mixed grass sites. Since that time, tarbush has increased in acreage, spreading onto both the black grama grassland and burrograss-tobosa grassland. There has been a greater reduction of grass cover on creosotebush and mesquite areas than on tarbush areas and the decline in grass cover is much slower on heavy soils than on light soils; however, there is a definite decline in grass cover on sites which have been heavily invaded by tarbush.

Grazing had little direct effect on the invasion of tarbush into burrograss and tobosa areas. Since tobosa and burrograss are relatively unpalatable except during the short growing season, it would take a large concentration of livestock to overgraze these areas. Had fires been prevalent on the Jornada plain, they might have been a factor in keeping tobosa areas free of brush. It is possible that under pristine conditions, tobosa was more restricted in area than at present due to the lower amounts of runoff associated with good grass cover on the slopes.

Tarbush seed is more motile than creosotebush and mesquite seed. This may have been a factor responsible for the early invasion of some sites by tarbush, even though it appears that creosotebush and mesquite are better adapted to those sites.

It is concluded that, given time, greater distribution of seed and further deterioration of the study area, creosotebush will be present in varying amounts on all soils of the study area. Grass cover will be negligible when creosotebush is dominate. Tarbush is invading grassland and although loss of grass cover is slow it is definite. Mesquite invasion has been rapid. The area dominated by mesquite was ten times as great in 1963 (66,153 acres) as in 1858 (6,266 acres). It has more than doubled since 1928.

SUMMARY

General Land Office Survey notes made in 1858 for the 144,475 acres in the study area on the Jornada Experimental Range were analyzed and compared with vegetation maps on ocular reconnaissance range surveys for the years 1915, 1928, and 1963. Comparisons were also made among the reconnaissance surveys. Acreages covered by mesquite, creosotebush, and tarbush, and their various combinations, were studied on the basis of the soil types on which they occurred.

In 1858 good grass was present on more than 90% of the study area. By 1963 less than 25% of the area had good grass. Mesquite has been present on all soil types. However, the main invasion of mesquite was on sandy soils. As mesquite begins to dominate a sandy site, low dunes form and grass cover is greatly reduced. In 1858 over 6,000 acres had abundant mesquite; by 1963 an area more than ten times as great was dominated by mesquite, with half of that increase occurring after 1928.

In 1858 isolated mesquite stands were present on the western part of the study area. Those areas were not in the immediate vicinity of stock water developments, but the initial spread was from these areas having mesquite in 1858. It was not until later years that mesquite became prevalent in the overgrazed areas around the wells even though the entire study area was heavily stocked from about 1904 to 1925. On the higher areas on the northeastern part of the Range, Indian activity contributed to the early formation of mesquite dunes before domestic livestock grazed on that area. Grazing by livestock occurred earlier there than farther out on the plain because stock water was available from springs in the nearby mountains. Mesquite seed dispersal by livestock was of great importance in the spread of mesquite to adjacent areas. Grass cover was reduced by livestock grazing and the occurrence of periodic droughts. With the introduction of seed, mesquite plants were readily established in the sparse grass cover. Once established, the grasses could not compete with the mesquite. Rodent and rabbit activity was a secondary factor in the spread of mesquite.

Only slight mesquite invasion has taken place on soils having gypsum in their profile. Creosotebush was not found on the gypsiferous soils in the study area; however, it has been observed on those soils in other areas. On the Jornada Experimental Range, creosotebush occurred mainly on the relatively shallow, coarser textured soils on slopes; however, it was present on all soil textures in the study area. The area dominated by creosotebush increased from about a section in 1858 to over 12,000 acres in 1963.

On the southeastern part of the study area, creosotebush was present in some areas in 1858; however, a good stand of grass was also present. With selective grazing of grasses by livestock and recurring droughts, the equilibrium on those drier sites between creosotebush and grass was shifted in favor of brush. As creosotebush increased, the soil surface became unstable and soil erosion increased. Since the major grass species in that area, black grama, is sensitive to deposition and erosion of soil, the grass cover was further reduced. With this reduced competition, creosotebush increased rapidly.

Tarbush has been present on all soils where creosotebush is growing, but creosotebush has not been present on all areas where tarbush dominates, while mesquite may or may not be present in these areas. Tarbush appears to move from the mixed grass areas with medium textured soils onto the adjacent lighter soils and grows in conjunction with mesquite. It also moves onto the heavier soils and grows in conjunction with tobosa and burrograss. Tarbush increased in acreage until 1928. Since 1928, creosotebush has invaded the tarbush areas. Livestock grazing is considered to have had little direct effect on the invasion

of heavy soils by tarbush. Fires could have been a factor; however, no extensive fires were reported.

The climate has not changed enough to be the major factor responsible for the rapid increase of brush species. However, only a slight change in the climate to warmer, drier conditions, in conjunction with grazing, could have some effect on vegetation changes in the drier portions of the semidesert grassland. Periodic droughts have been a factor in reducing grass competition so that brush species can become established. Fire was not considered to be a factor in the maintenance of brush-free range. Rodent and rabbit activity was a secondary factor in the spread of brush. Seed dispersal, accompanied by heavy grazing and periodic droughts, appeared to be the major factor affecting the rapid increase of shrubs.

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