A QUANTITATIVE ECOLOGY OF THE JORNADA EXPERIMENTAL RANGE[1]

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BACKGROUND INFORMATION

The area including the Jornada Range has been classified as semidesert grassland. The semidesert grassland extends over southeastern Arizona, southern New Mexico, western Texas, and northern Mexico (the desert grassland of Shreve (1917) and Shantz and Zon (1924), and the desert plains of Clements (1920)). The semidesert grassland does not occupy that entire area but occurs rather widely interspersed with other types. It occupies extensive plains areas, but it also typically occurs as broad belts around the base of many of the southwestern mountain ranges.

Although the region is termed "grassland", it is far from being an essentially unbroken expanse of grasses, as are the tall and mixed grass prairies. In some places pure stands of grass prevail; in others there are open savannas with grasses associated with oaks or mesquites. In still other places the grasses are interspersed with a wide variety of low-growing trees or shrubs. Annual and perennial grasses and forbs, and shrubs are common.

The semidesert grassland has long been considered as a climatically determined climax (Clements 1920, Campbell 1929, Whitfield and Anderson 1938, Whitfield and Betner 1938, Clements and Shelford 1939, Gardner 1951). Shreve (1917) regarded the area as transitional between a true grassland to the east and the shrub deserts to the west and south. On the basis of changes in a protected grassland area, Brown (1950) concluded that semidesert grassland was not climax but was maintained in part by some factor that was unfavorable

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to shrubs. Canfield (1948) and Buffington and Herbel (1965) found that once unpalatable woody plants are established they become a relatively permanent part of the plant cover. More stable areas can undoubtedly be classified as grassland but other large areas would have to be classified as desert shrub or Chihuahuan Desert.

Climate

The semidesert grassland is the most arid of all North American grassland regions. Mean annual precipitation is low - ranging from 8 - 14 inches. Most of the precipitation in the area occurs as rain. Over the eastern third of the region at least 70% of the annual precipitation occurs from April 1 to September 30. Further west this percentage decreases until on the western edge in south-central Arizona about 45% of the annual precipitation occurs during this 6-month period. In the western part of the region, there are 2 precipitation peaks; the summer rains occur primarily in July and August while the winter rains occur from December to February. In the central part of the region, as at the Jornada Range, most of the precipitation occurs during the July - October period (Table 1). Over the entire region, summer moisture originates in the Gulf of Mexico and it is largely in the form of intense, convectional thunderstorms - highly localized and of short duration. Winter storms originate in the Pacific Ocean and they are characterized by relatively gentle precipitation, fairly generalized, that may last for several days.

Table 1. Average climatic features at Headquarters, Jornada Experimental Range.

Month	Precipitation[1/]	Temperature[2/] Maximum	Temperature[2/] Minimum	Evaporation[3/]	Wind Movement[4/]
	In.	F.	F.	In.	mi.
January	0.45	56	22	2.4	595
February	0.38	62	26	3.8	749
March	0.34	68	31	6.9	1,332
April	0.21	76	39	9.7	1,488
May	0.41	85	46	12.1	1,272
June	0.50	95	56	13.4	1,144
July	1.67	94	64	11.5	770
August	1.71	93	62	10.0	665
September	1.31	88	54	8.2	497
October	0.96	78	42	5.7	487
November	0.40	65	28	3.3	466
December	0.57	56	22	2.3	607
Annual	8.91	76	41	89.4	10,072

[1/] 1914-60 [2/] 1919-60 [3/] 1938-60 [4/] 1950-56

Temperatures are relatively high over the region. Average temperatures may be somewhat misleading because the temperature drops quickly in the early morning hours and then increases rapidly shortly after sunrise. On the Jornada Range, the average annual temperature is 59 F and the July average is 79 F (Table 1).

Average annual evaporation from a Weather Bureau pan at the Jornada is 89.4 inches (Table 1). It is particularly high in the months of May - July. Wind movement averages one and one-half to two mph at the Jornada from March through June (Table 1). For the remainder of the year, it ranges from 2/3-1 mph.

Physiography

The Jornada plain consists of unconsolidated Pleistocene detritus (Veatch 1918). This alluvial fill from the nearby mountains is about 300 feet thick in places and in certain areas the aggradation process is still active. Coarser materials are found near the foothills along the eastern part of the study area, and the heaviest-textured soils are found in the old lake beds. The Dona Ana Mountains are a complex mass of Tertiary rhyolitic to andesitic volcanics with intruded monzanites. The San Andres Mountains are a west-tilted fault block composed mainly of Paleozoic marine sediments, primarily limestones, but also sandstones and shales. Prominent gypsum beds are present in the Paleozoic rock sequence. The topography of the plain on the Jornada Range consists of nearly level to gently rolling uplands, interspersed with swales and old lake beds. Rough, steep terrain occurs in the mountains and foothills. Elevations vary from 4,200 to 8,500 feet. Twenty-two soil types ranging from loamy sands to clays have been mapped (Soil Conservation Service 1963, revised 1967).

Vegetation

The main grass species on sandy soils on the study are black grama (Bouteloua eriopoda (Torr.) Torr.), mesa dropseed (Sporobolus flexuosus (Thurb.) Rydb.), and red threeawn (Aristida longiseta Steud.). Shrub species growing on the sandy soils are honey mesquite (Prosopis juliflora (Swartz) DC. var glandulosa (Torr.) Cockerell) and fourwing saltbush (Atriplex canescens (Pursh) Nutt.). Other shrublike plants are soaptree yucca (Yucca elata Engelm.) and broom snakeweed (Gutierrezia sarothrae (Pursh) Britt. and Rusby). In the lowerlying areas, the main grass species are tobosa (Hilaria mutica (Buckl.) Benth.) and burrograss (Scleropogon brevifolius Phil.). Tarbush (Flourensia cernua DC.) has invaded the heavier soils. The upper piedmont slopes of the mountains are dominated by creosotebush (Larrea tridentata (DC.) Coville).

Stocking History

In 1858, surveyors of the United States General Land Office mentioned that the farmers in the Rio Grande River valley put livestock up on the Jornada Plain near the mountains for summer grazing because of available spring water (Buffington and Herbel 1965). There were several springs in the San Andres Mountains which border the Jornada Range on the east 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 ranches. In 1883 the Goldenburg brothers started a ranch at a spring in the San Andres Mountains. In 1887 they were forced to move about 2 miles west of the spring because of constant pilferage by Indians. Their cattle were pushed far out on the plains to graze often as far as Flat Lake, about 2 miles from the northwest corner of the Jornada Range. About one and one-half miles south of the Goldenburgs, Horace Ropes took over a mining claim and spring and stocked with 500 cattle. He constructed 3 miles of waterway toward the plain which lasted only a couple of years because the growing mesquite roots broke it up. Ropes' cattle ranged nearly to the Rio Grande River. He sold out to the Goldenburgs in 1893. Goldenburg Ranch had about 1,800 cattle in 1900. These seem to have been the main sources of grazing pressure along the east side of the Jornada Range.

The Bar Cross Ranch, organized about 1886, operated on most of the southern half of the Jornada Plain until about 1903. They harvested hay on the Jornada Plain indicating that stocking was not too great or that hay was harvested on areas inaccessible to livestock. In 1888 the Bar Cross 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 miles out on the plain to the east or about 3 miles west of the Jornada Experimental Range boundary.

The first water wells on what is now the Jornada Range were drilled in 1903-1905. They were Red Lake Well, Headquarters Well, South Well, and Taylor Well. Mr. C. T. Turney bought the water rights on most of the Jornada Range from 1904-1912. He had about 3,000 cattle. In 1912, with Turney's concurrence, the Jornada Range Reserve was established by Executive Order. E. O. Wooten of the Bureau of Plant Industry was instrumental in recommending the establishment of this experimental area, and Turney fenced the area immediately and retained grazing privileges until 1925.

From May, 1915 to May, 1916, the average number of livestock grazing on the Jornada Range was 4,632 head on about 192,000 acres. Jardine and Hurtt (1917) reported that while this was too many, no supplemental feed would be needed if only 4,000 head were stocked. According to Paulsen and Ares (1962), there was an average of 2,340 animal units on the Jornada from 1916-1926. 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 Range was reduced to 105,700 acres for grazing purposes. That, coupled with a severe drought, reduced the average stocking for the 1954-1957 period to an average of 123 cattle. In recent years stocking has averaged about 450 animal units.

Wildlife

The predatory mammals inhabiting the area include the coyote (Canis latrans), gray fox (Urocyon cinereourgentens), desert fox (Vulpes macrotis), badger (Taxidea taxus), bobcat (Lynx rufus), and striped skunk (Mephitis mephitis). All of these, with the exception of the foxes and the badger, can be considered common to abundant (Wood 1969). Other large mammals occurring on the plain are the antelope (Antilocapra americana), and in the mountains are mule deer (Odocoileus hemionus).

The rodents occurring on the area (Wood 1965) are: Ord's kangaroo rat (Dipodomys ordii), Merriam's kangaroo rat (D. merriami), banner-tailed kangaroo rat (D. spectabilis), White-throated wood rat (Neotoma albigula), southern plains wood rat (N. micropus), silky pocket mouse (Perognathus flavus), penicillate pocket mouse (P. penicillatus), spotted ground squirrel (Citellus spilosoma), grasshopper mouse (Onychomys leucogaster), white-footed mouse (Peromyscus maniculatus), cotton rat (Sigmodon hispidus), and harvest mouse (Reithrodontomys megalotis). Other small mammals are the desert cottontail (Sylvilagus audoboni), blacktailed jackrabbit (Lepus californicus), big brown bat (Eptesicus fuscus), and the pallid bat (Anthrozous pallidus).

Some of the primary birds are the roadrunner (Geococcyx californicus), marsh hawk (Circus cyaneus), redtailed hawk (Buteo jamaicensis), Swainson's hawk (B. swainsoni), shorteared owl (Asio flammeus), burrowing owl (Specotyto curicularia), mourning dove (Zenaidura macroura), Gambel quail (Lophortyx gambelli), and scaled quail (Callipepla sqnamata).

Some of the common reptiles and amphibians are: prairie rattlesnake (Crotalus viridis), diamondback rattlesnake (C. atrox), Texas horned lizard (Phrynosoma cornutum), and tiger salamander (Ambystoma tigrinum).

On the study area, species of animals that could be capable of effecting vegetation are; rabbits, rodents, antelope, mule deer, foxes and coyotes. The most important damage to vegetation apparently comes from the rodents (Wood 1969) and rabbits. Antelope are not abundant enough to have much effect on the vegetation (Engelking 1969) and mule deer only occur in the mountains and foothill areas. Coyotes and foxes occasionally eat the seeds of such desirable plants as fourwing saltbush (Rogers 1965), but this is a small amount of their diet and probably has very little, if any, detrimental effect on vegetation.

However, rodents and rabbits are very abundant on the area and are capable of consuming large amounts of vegetation (Wood 1969, and Currie and Goodwin 1966). Their influence on vegetation may even be enough to prevent recovery of the range after overgrazing or severe drought has occurred (Norris 1950). Details pertaining to amounts and types of vegetation eaten and destroyed will be covered in the section on livestock and wildlife relationships.

Insects

One hundred thirty-six species of insects were collected on black grama by Watts (1963). Chirothrips falsus was the principal species limiting seed production (Watts 1965). Black grama seed yields were increased signigicantly by thrips control. It also seems likely that some of the other grasses on the Jornada Range may have insect damage to developing seed (Watts and Bellotti 1967). Harvester ants are avid collectors of grass seed. Very little insect damage to plant parts of grasses other than seed heads has been observed.

MICROCLIMATE OF SELECTED SITES

Soil Moisture - Precipitation Relationships

At several locations, gypsum soil moisture units were placed at depths of 4, 10, 16, 24, 36, and 48 inches, or to the caliche layer if it occurred at shallower depths. Soil moisture was recorded throughout the year beginning in 1957. It was generally recorded 2 or 3 times a week during the summer growing season and 1 or 2 times a month for the remainder of the year.

At the sandy sites, such as West Well, Ber rain gauge, and Exclosures A and B, it generally took 0.50 to 0.70 inches precipitation to decrease the soil moisture tension at the 4 inch depth from greater than 15 bars to less than 1 bar. On some occasions it took more than 1 inch precipitation to decrease the soil moisture tension to less than 1 bar without showing available soil moisture at the 10 inch depth. It generally took a total of 1.25 to 1.50 inches and on occasion 1 inch of precipitation within about 10 days to decrease the soil moisture tension to less than 1 bar at both the 4 and 10 inch depths. It generally took a total of 1.75 to 2.25 inches and occasionally 1.25 inches within about 10 days to decrease the soil moisture tension from greater than 15 bars to less than 1 bar at the 4, 10, and 16 inch depths. At Exclosure B, widely spaced rains of about 1 inch per day in the summer of 1965 only resulted in moisture tension of less than 1 bar at the 4 inch depth. In 1964, widely spaced rains of 1.36 to 1.52 inches resulted in some available soil moisture down to the 32 inch depth. It therefore apparently takes about 1.3 inches precipitation to obtain deep moisture without some pre-wetting.

On the clay loam tobosa sites, such as the exclosures at the south boundary and north of Headquarters, it generally took 0.75 to 1.25 inches of precipitation, excluding run-in, to moisten dry soil down through the 4 inch depth. North of Headquarters, rainfall in the amounts of 2.36 and 2.27 inches in 1961 and 1962, respectively, moistened dry soil to the 10 inch depth. In 1961, another storm of 2.84 inches moistened the dry soil to a depth of 16 inches where run-in was excluded. At the south boundary, rainfall of 2.86 inches moistened the dry soil to a depth of 48 inches in 1963. When run-in was included, it was not uncommon for the tobosa sites to have available soil moisture down to the 48 inch depth for part of the summer growing season.

When run-in was excluded from the burrograss site at the south boundary, individual storms ranging from 0.68 to 2.86 inches only moistened dry soil to the 4 inch depth. When run-in was not excluded, available soil moisture was observed infrequently down to the 48 inch depth. On both the tobosa and burrograss sites, run-in contributed 75 to 90% of the observed available soil moisture. Examples chosen to illustrate these points are given in Figure 1.

In seeding studies, soil moisture in the surface 4 inches was measured with fiber glass soil moisture units, 2 or 3 times a week, for several summers (Herbel 1969). Figure 2 shows the daily precipitation and soil moisture tension at the 0.5 and 4 inch depths on a sandy site under bare soil surface conditions at Yucca Rain Gauge in 1959. There were only 7 days with readily available soil moisture (less than 1 bar tension) at the 0.5 inch (1.3 cm) depth even though there was 7.9 inches (20.1 cm) precipitation during the 80-day period from June 29 to September 16. Moisture tension was between 1 and 15 bars for 12 days; between 15 and 24 bars 14 days; and greater than 24 bars for 47 days. At the 4 inch (10.2 cm) depth soil moisture was readily available for 30 days, and between 1 and 15 bars for 28 days.

On a clay loam site there were 5 inches (12.7 cm) of precipitation; there was no readily available soil moisture at the 0.5 inch depth because the surface dried very rapidly following precipitation (Fig. 3). Moisture tension was between 1 and 15 bars for 9 days; between 15 and 24 bars for 9 days; and greater than 24 bars for 62 days. At the 4 inch depth there were 4 days when soil moisture tension was less than 1 bar and also between 1 - 15 bars.

In another trial in 1962, soil moisture was recorded at the 0.5 inch depth on a clay loam site infested with tarbush. The area was rootplowed for tarbush control and soil moisture was measured under the light brush cover and an adjacent rootplowed area with no cover (Fig. 4). During the 82-day period from July 1 - September 20, 5.8 inches (14.7 cm) rainfall was recorded. There were 5 days with available soil moisture (less than 15 bars tension) at the 0.5 inch depth on the area with no cover and 42 days on the area with brush cover. At the 4 inch depth (not shown in the figure) there was available soil moisture for 33 days on the check and 74 days under brush cover.

On sandy sites, available soil moisture is effectively stored below the 6 inch depth after about November 1 until the next spring. The surface soils are coarse textured and there is little capillary movement of moisture in the surface soil. On clay loam sites, soil moisture may be lost rather rapidly by surface evaporation, even from the 48 inch depth.

Air - Soil Temperature Relationships

Even though maximum daily temperatures in a Weather Bureau shelter in the summer rarely exceed 100 F, surface soil temperatures are very high because of intense solar radiation. Air temperatures were recorded at 4 inches above the soil surface in a shelter with free air movement and soil temperatures at varying depths for several years (Herbel 1969). Figure 5 shows the average daily air temperature and soil temperature at the 0.5 inch depth for the period of July 28 - August 15, 1964. The minimum air temperature averaged 67 F (19 C) and the maximum averaged 92 F (33 C). With no surface cover, the maximum soil temperature averaged 135 F (57 C). With light cover (1 dead tarbush plant), the maximum soil temperature averaged 119 F (48 C). With heavy soil cover (3 dead tarbush plants), the maximum soil temperature averaged

Figure 1. Precipitation and soil moisture at selected sites.

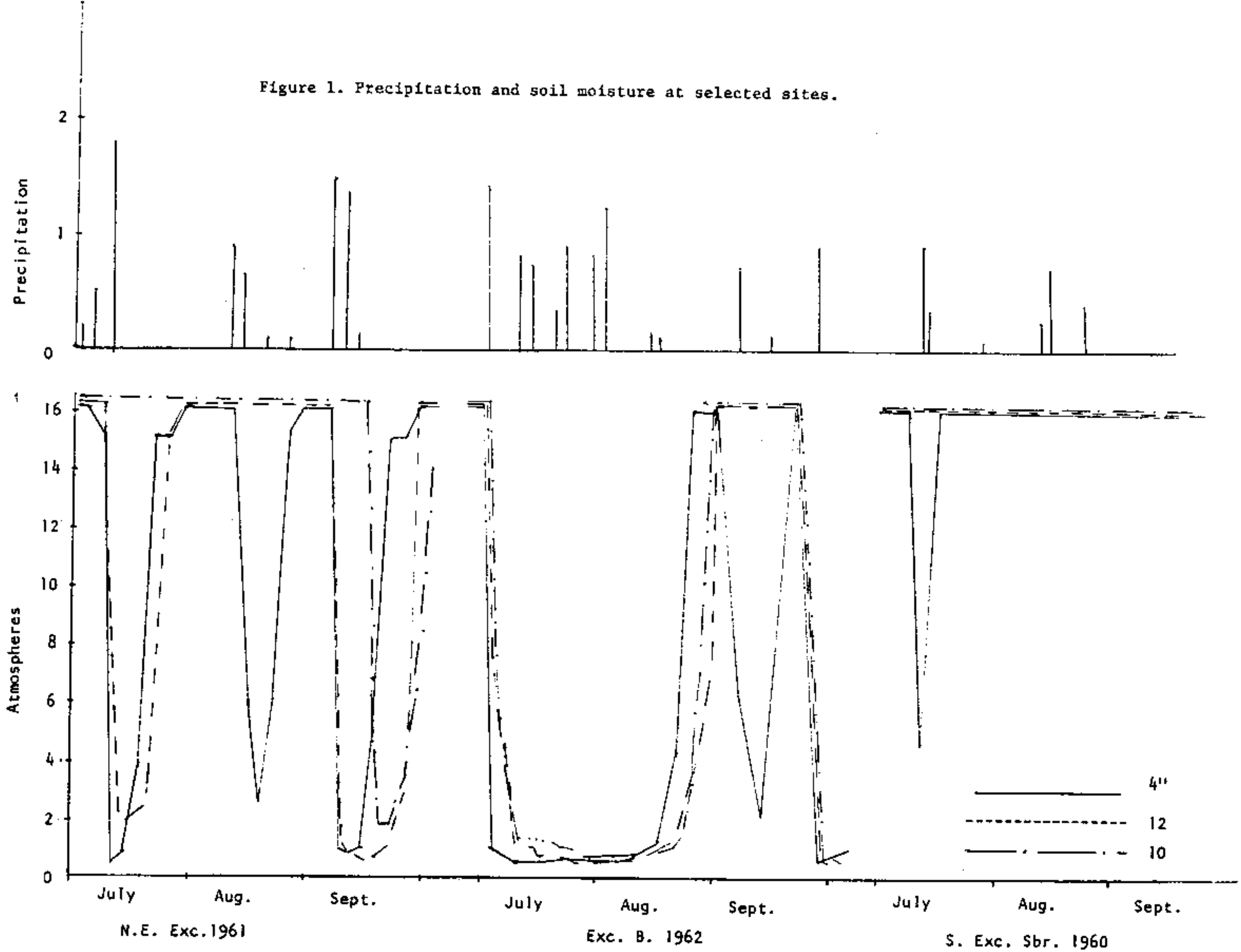


Figure 2. DAILY PRECIPITATION AND SOIL MOISTURE TENSION

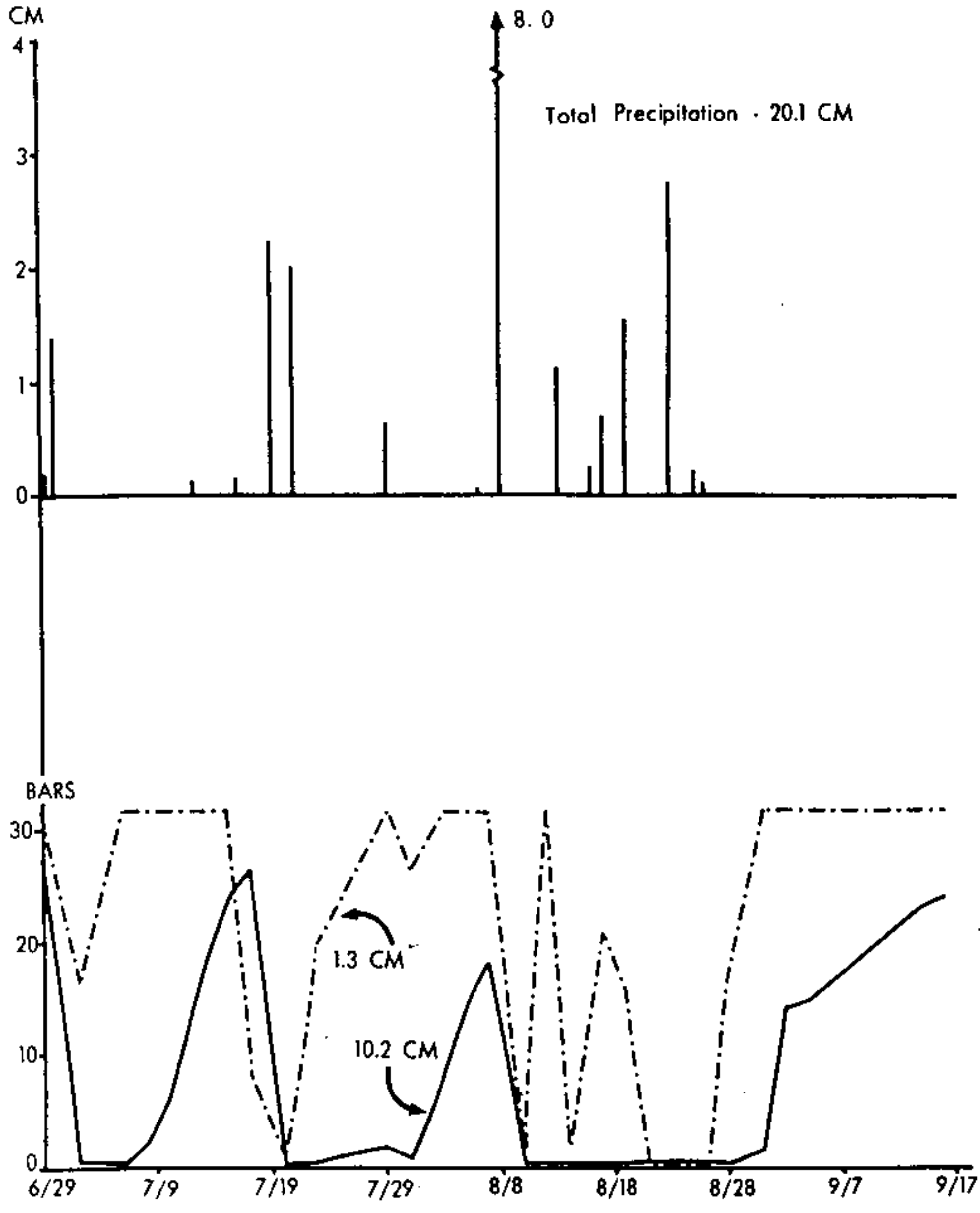


Figure 3. DAILY PRECIPITATION AND SOIL MOISTURE TENSION

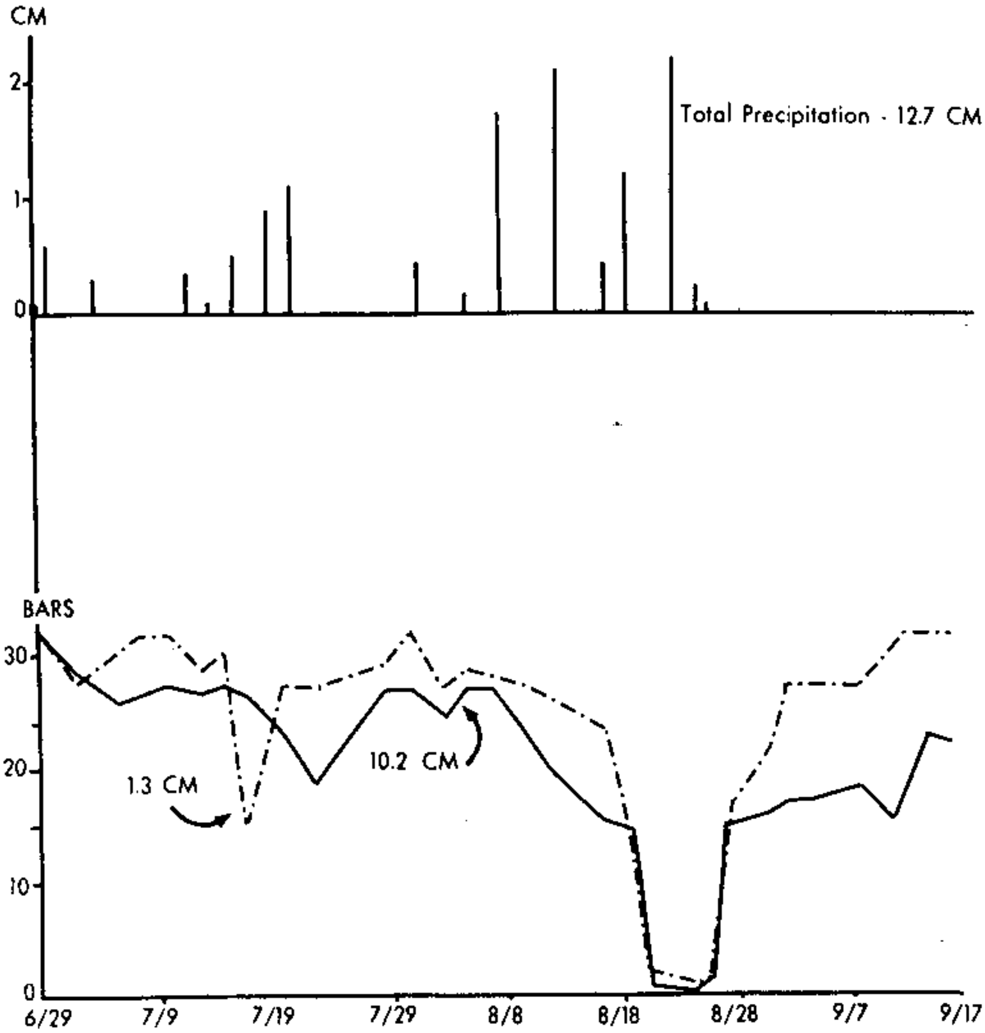


Figure 4.
DAILY PRECIPITATION AND SOIL MOISTURE TENSION (1.3 CM Depth)

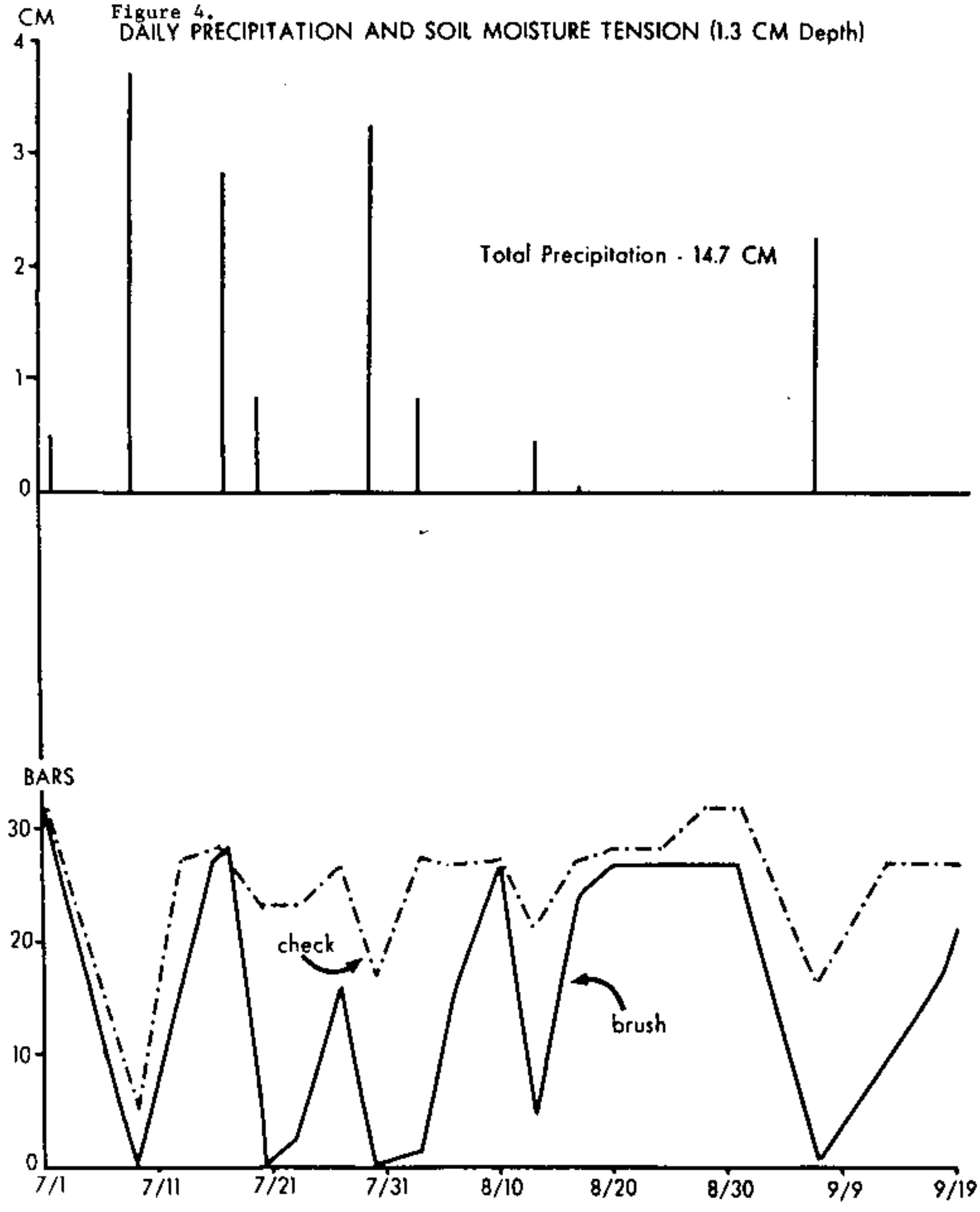
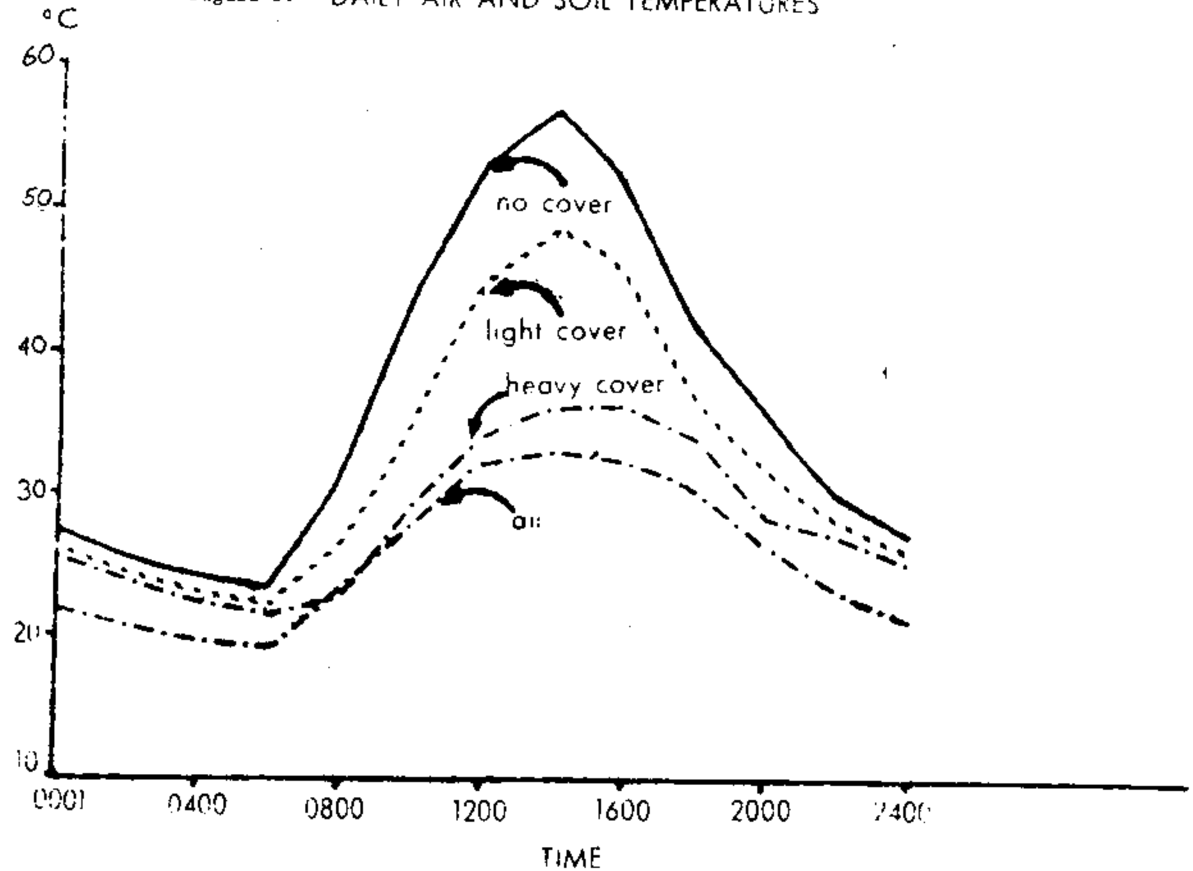


Figure 5. DAILY AIR AND SOIL TEMPERATURES



97 F (36 C). Soil temperatures of 150 F have been recorded at the half inch depth during the summer when the soil is dry. In the winter when the soil is moist, minimum daily soil temperatures generally are no lower than 30 F. However, if the soil is dry, minimum temperatures may drop to about 20 F at the 12 inch depth.

Evaporation from Black and White Atmometers

Temperature and water relations of organisms are generally more influential in differentiating the physiological potentialities of different habitats than any other environmental factors. The environmental condition that influences ordinary plants beneath the soil surface is the water-supplying power of the soil. The corresponding influence above the soil surface is evaporativity (Livingston 1935). This is a complex of air temperature, air humidity, air movement, and radiation. Black and white atmometers, 4 inches above the surface of the ground, were in operation during the summer of 1957-61. Halkias et al. (1955) developed the following formula:

Evaporation from pan, in inches = 0.0051 evaporation from white atmometer, in ml.

Table 2 shows the average daily evaporation for selected July and August dates for 1957-61. For each of the 5 years, except 1959, there was good agreement between the average daily evaporation from the Weather Bureau pan at Headquarters and the white atmometers. During 1959 evaporation from black and white atmometers was about half that of the pan. A possible explanation is the extremely wet conditions in July and August which may have reduced evaporation from atmometers but did not influence the evaporation from the pan. The evaporation at Stuart Rain Gauge (good condition tobosa) was lower than other locations. Omitting 1959 data, the evaporation at other atmometer sites was 21 - 28% higher than at Stuart. Dona Ana is a creosotebush site; Exclosure A is drought-depleted, poor condition sandy land site; Exclosure B is a fair condition sandy land site; and Rabbit Rain Gauge is a mesquite sand dume site. Average daily evaporation at Headquarters, a poor condition grassland site, was 12% greater than at Stuart.

Table 2. Average daily evaporation from a Weather Bureau pan at Headquarters and 0.0051 evaporation from white atmometers in ml at 5 locations.

Location	1957	1958	1959	1960	1961
	in.	in.	in.	in.	in.
Headquarters	0.33	0.40	0.34	0.39	0.37
Rabbit Rain Gauge	0.31	0.46	0.17	0.41	0.40
Exclosure B	0.39	0.46	0.18	0.40	0.43
Exclosure A	0.34	0.46	0.16	0.38	0.48
Dona Ana	--	0.47	0.14	0.41	0.45
Stuart Rain Gauge	0.26	0.35	0.13	0.31	0.38

Halkias et al. (1955) also developed the following relationship: mean monthly difference in evaporation between black and white atmometers, in ml = 0.028 mean monthly radiation, in gram calories per square centimeter. Table 3 shows the average daily radiation for selected July and August dates for 1957-61.

Table 3. Average daily radiation (gram calories per square centimeter) as estimated by black and white atmometers.

Location	1957	1958	1959	1960	1961
			gm cal/sq cm		
Rabbit Rain Gauge	554	596	1007	586	725
Exclosure B	568	621	775	575	511
Exclosure A	689	732	668	607	521
Dona Ana	-	829	1579	557	768
Stuart Rain Gauge	471	625	807	725	818

PLANT GROWTH PHENOMENA

Germination and Initial Growth

Black grama, bush muhly (*Muhlenbergia porteri* Scribn.), tobosa, mesa dropseed, lehmann lovegrass (*Eragrostis lehmanniana* Nees), and boer lovegrass (*E. chloromelas* Steud.) caryopses were germinated in water-mannitol solutions of 0.3, 3, 7, 11, 15, and 20 atm moisture stress (Knipe and Herbel 1960). With the exception of leimann lovegrass, time required to germinate was not greatly increased by increasing osmotic concentration from 0.3 to 7 atm. However, total germination of lehmann lovegrass, boer lovegrass, and mesa dropseed was significantly reduced by increasing osmotic concentration from 0.3 to 7 atm, and reduction in total germination of the other species was very nearly significant under these conditions. Generally, the growth of seedlings was significantly reduced by increasing osmotic concentration from 0.3 to 7 atm. Of the species tested, black grama and bush muhly seem best adapted to survival under conditions of limited moisture. Seedlings of these species were the only ones which attained measurable growth in an 11-atm solution. None of the species developed measurable seedlings at 15 and 20 atm, but the caryopses of black grama and bush muhly germinated very well at these levels.

The effects of 2 temperature regimes and 5 moisture levels on emergence and initial growth of black grama and boer lovegrass were studied in controlled light-temperature chambers (Herbel and Sosebee 1969). The maximum daily soil temperatures ranged from 128 to 152 F in the high temperature regime, and from 101 to 123 F in the low temperature regime, depending on moisture level. The daily minimum temperatures were about 77 F in all treatments. The five soil moisture levels were determined as a portion of the volume required to maintain field capacity conditions. Level A was approximately field capacity; Levels B and C were watered as level A on the planting day, and then reduced to about a half and a third of level A for the remainder of the 21-day trial. Levels D and E were watered as level A for the first 3 days, and then reduced to about a half and a third of Level A for the remainder of the trial.

In the high temperature regime black grama did not emerge at moisture levels B and C; and boer lovegrass did not emerge at levels B, C, and E. In addition, boer lovegrass did not emerge in the low temperature regime at moisture level C. Survival of emerging seedlings ranged from 0 to 4.7% in the high temperature regime at all moisture levels except A (Table 4). Reduced soil moisture, a day after planting, was more detrimental to survival than reducing soil moisture the third day after planting. Survival of black grama at moisture level A in the high temperature regime was not adversely affected by the high leaf temperatures (178 F). The shoot lengths (Table 5) and weights of surviving black grama seedlings were always greater than those of boer lovegrass. Under the conditions of this 21-day trial it took about 2.8 inches of water for either species to survive in the low temperature regime and about 9.1 inches to survive in the high temperature regime.

In another light chamber study, the daily soil temperatures were patterned after observations made under field conditions; 65 to 103 F where the surface was sparsely shaded by brush, and 65 to 128 F where the surface was left bare (Sosebee and Herbel 1969). The soil moisture was maintained at field capacity. Emergence of sacaton (Sporobolus wrightii Munro), vine mesquite (Panicum obtusum HBK.), bush muhly, and fourwing saltbush was adversely affected by the high temperature regime. Survival of all 14 accessions except rhodesgrass (Chloris gayana Kunth), 'Vaughn' sideoats grama (Bouteloua curtipendula (Michx.) Torr.), and black grama was reduced by the high temperature regime (Table 6).

At the close of the 21-day trial most species had

TABLE 4. AVERAGE SURVIVAL (%) OF EMERGING SEEDLINGS ON THE 21st DAY AFTER PLANTING FOR TWO SPECIES WITHIN TWO SOIL TEMPERATURE REGIMES AT FIVE SOIL MOISTURE LEVELS. 1/

Species	Temperature	Moisture A	B	C	D	E
Black grama	High	B 66.6	-	-	A 4.7a	A 0 a
	Low	B,C 89.7a,b	B 79.9b	A 16.5	C 97.1b	B,C 95.2b
Boer lovegrass	High	B 41.4a	-	-	A 0 a	-
	Low	B 100.0b	A 28.0a	-	B 100.0b	B 100.0b

TABLE 5. AVERAGE SHOOT HEIGHT (CM) ON THE 21st DAY AFTER PLANTING FOR TWO SPECIES WITHIN TWO SOIL TEMPERATURE REGIMES AT FIVE SOIL MOISTURE LEVELS. 1/

Species	Temperature	Moisture A	B	C	D	E
Black grama	High	B 4.1b	-	-	A 0.5a	-
	Low	D 6.8d	B 5.2b	A 0.5	C 6.0c	B 4.9b
Boer lovegrass	High	1.2a	-	-	-	-
	Low	C 5.3c	A 0.7a	-	B 2.8b	B 2.8a

1/ Capital letters are used to compare means on the same line. Lower case letters are used for comparisons of means (1) between temperatures within species and (2) between species within temperatures. Entries having the same letters are not significantly different (0.05 level). A dash (-) indicates no surviving seedlings.

TABLE 6. AVERAGE SURVIVAL (%) OF EMERGING SEEDLINGS ON THE 21st DAY AFTER PLANTING FOR 14 SPECIES WITHIN TWO SOIL TEMPERATURE REGIMES. 1/

Species	Temperatures			
	High		Low	
Rhodesgrass	A 90.0	a	A 100.0	a
Vaughn sideoats grama	A 80.5	a,b	A 83.7	a
Black grama	A 70.2	a,b,c	A 82.9	a
NM-28 Sideoats grama	A 60.2	b,c,d	B 94.1	a
Alkali sacaton	A 57.7	b,c,d	B 93.4	a
Vine mesquite	A 46.1	c,d,e	B 100.0	a
Boer lovegrass	A 46.0	c,d,e	B 93.5	a
Tobosa	A 44.5	c,d,e	B 94.3	a
Lehmann lovegrass	A 40.6	d,e	B 100.0	a
Sacaton	A 39.7	d,e	B 94.1	a
Caucasian bluestem	A 37.5	d,e	B 92.1	a
Yellow bluestem	A 23.0	e,f	B 90.8	a
Bush muhly	A 4.9	f	B 93.9	a
Fourwing saltbush	A 0.0	f	B 98.1	a

1/ Capital letters are used to compare means on the same line and lower case letters are used to compare means in the same column. Entries having the same letter are not significantly different (0.05 level).

stopped growing or were growing very slowly under the high temperature regime (see Table 7 for shoot height data). The shoot weights for the plants growing in the low temperature regime averaged nearly twice as much as those growing in the high temperature regime. There was no significant difference in root weight/seedling between temperature regimes. The root lengths of black grama, 'Vaughn' sideoats grama, tobosa, lehmann lovegrass, and alkali sacaton (*Sporobolus airoides* (Torr.) Torr.) were not reduced significantly by the high temperature regime. The high temperatures were detrimental, in one way or another, to all species even when moisture was adequate but black grama and sideoats grama performed satisfactorily.

TABLE 7. AVERAGE SHOOT HEIGHT (CM) ON THE 21st DAY AFTER PLANTING FOR 14 SPECIES WITHIN TWO SOIL TEMPERATURE REGIMES. 1/

Species	Temperature			
	High		Low	
Vaughn sideoats grama	A 8.4	a	B 12.1	a
NM-28 sideoats grama	A 5.3	b	B 11.3	a
Black grama	A 4.5	b	B 7.0	b
Tobosa	A 3.4	b	B 11.7	a
Boer lovegrass	A 1.8	c	A 3.7	d,e
Vine mesquite	A 1.8	c	B 6.7	b,c
Sacaton	A 1.3	c	B 4.1	d,e
Rhodes grass	A 1.3	c	B 5.7	b,c,d
Alkali sacaton	A 1.1	c	B 4.1	d,e
Lehmann lovegrass	A 1.1	c	A 2.7	e
Caucasian bluestem	A 0.9	c	B 3.6	e
Yellow bluestem	A 0.9	c	B 6.5	b,c
Bush muhly	A 0.9	c	B 5.4	c,d
Fourwing saltbush	A 0.0	c	B 4.9	d

1/ Capital letters are used to compare means on the same line and lower case letters are used to compare means in the same column. Entries having the same letter are not significantly different (0.05 level).

Vegetation - Precipitation Relationships

Since the 1957-59 period, cover and yield estimates of the perennial grasses have been collected each fall at selected sandy sites. The pasture 9 site is an excellent condition black grama area on Simona sandy loam; about 90% black grama and 10% mesa dropseed. Pasture 2 is a good condition black grama site on Simona sandy loam; about 63% black grama, 35% mesa dropseed, and 2% red threeawn. Exclosure B is a good condition black grama site on Cacique sandy loam with about the same species composition as pasture 2. Pasture 11 is a poor condition site on Berino loamy sand; about 85% mesa dropseed, 13% red threeawn, and 2% black grama. Figures 6-13 show the relationships among cover, yield, and precipitation for the 4 locations (2 graphs for each location). One graph shows the relationships among yield, cover, and nonseasonal precipitation (total for the months January - June and October - December). This graph examines the relationships between basal cover and annual, seasonal, and nonseasonal precipitation. The most consistent relationship was between cover and nonseasonal precipitation. The second graph at each location shows the relationship between yield and seasonal precipitation, July - September. Generally, the relationship is good but where it is not, the relationship can be improved by including cover.

Yield estimates of tobosa and burrograss were obtained each fall for 1957-68. The tobosa area at the south boundary and the fertilization study area are both located on Stellar clay loam. The burrograss area at the south boundary is located on Reagan clay loam. The area north of Headquarters is located on Reeves loam. The 3 locations receive run-in water from occasional summer storms. Both the exclosure at the south boundary and the fertilizer exclosure are on a slight slope so that water does not

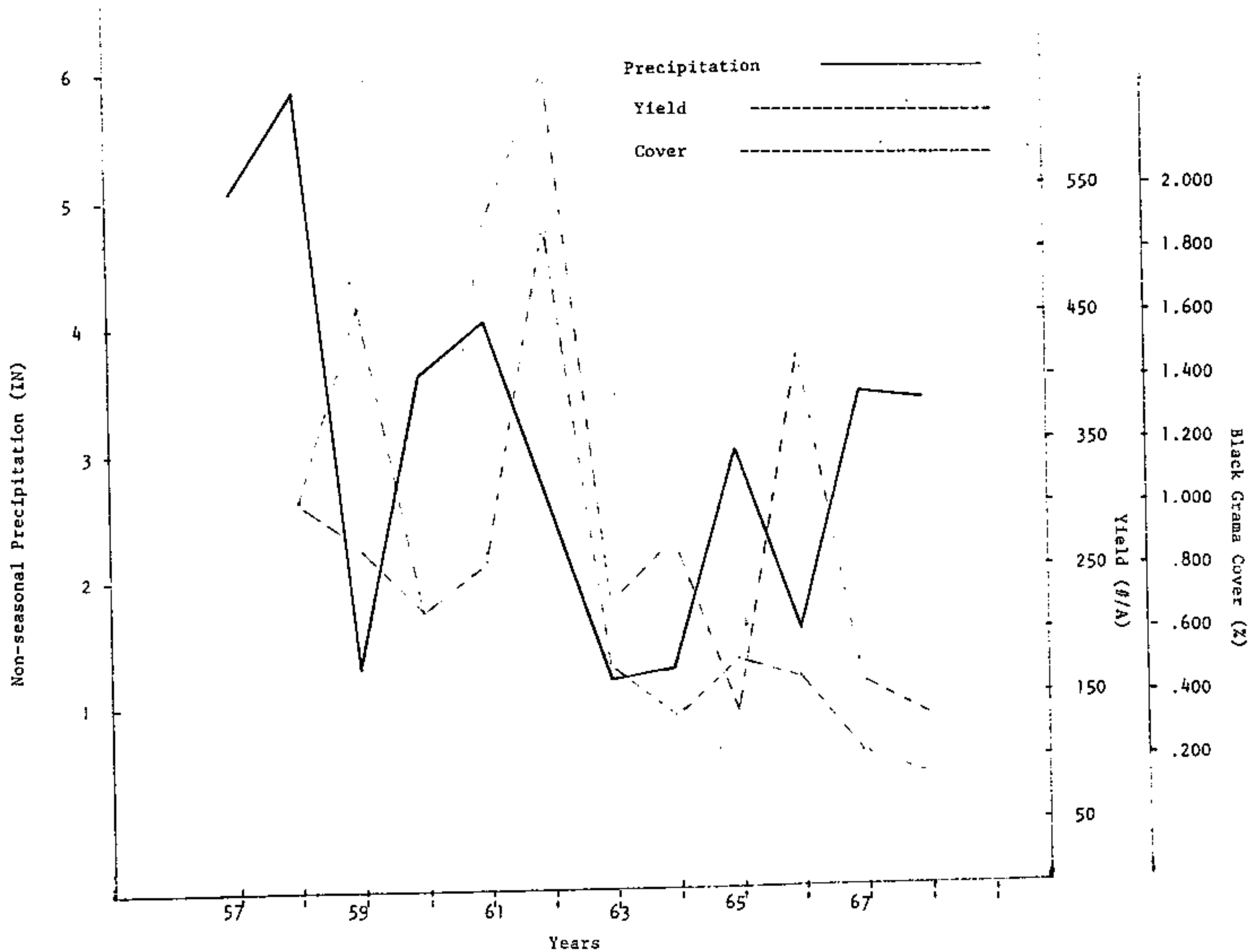


Figure 6. Black grama cover, Perennial grass yield and nonseasonal precipitation for 1957-68 in excellent condition black grama area in pasture 9.

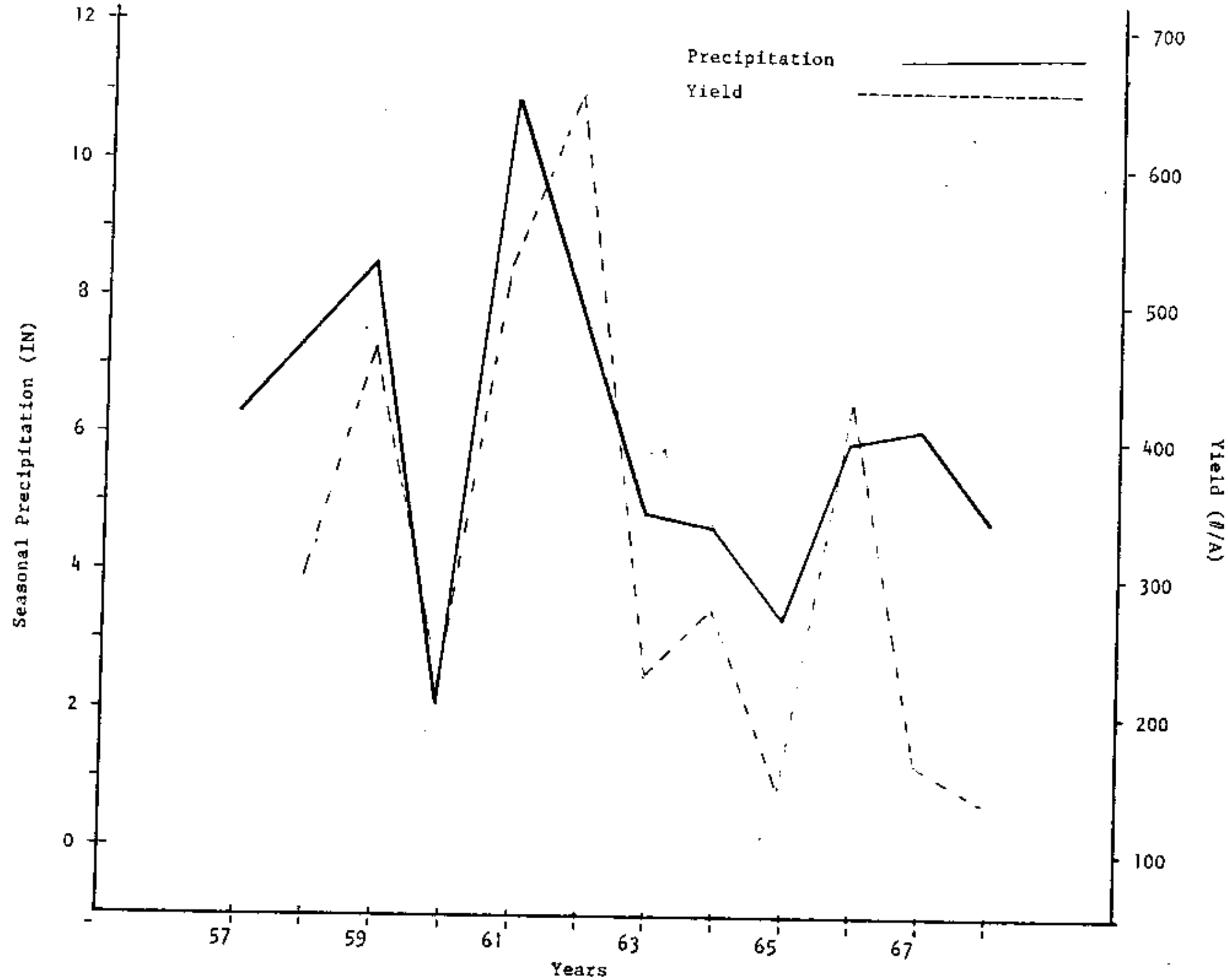


Figure 7. Perennial grass yield and seasonal precipitation for 1957-68 in excellent condition black grama area in pasture 9.

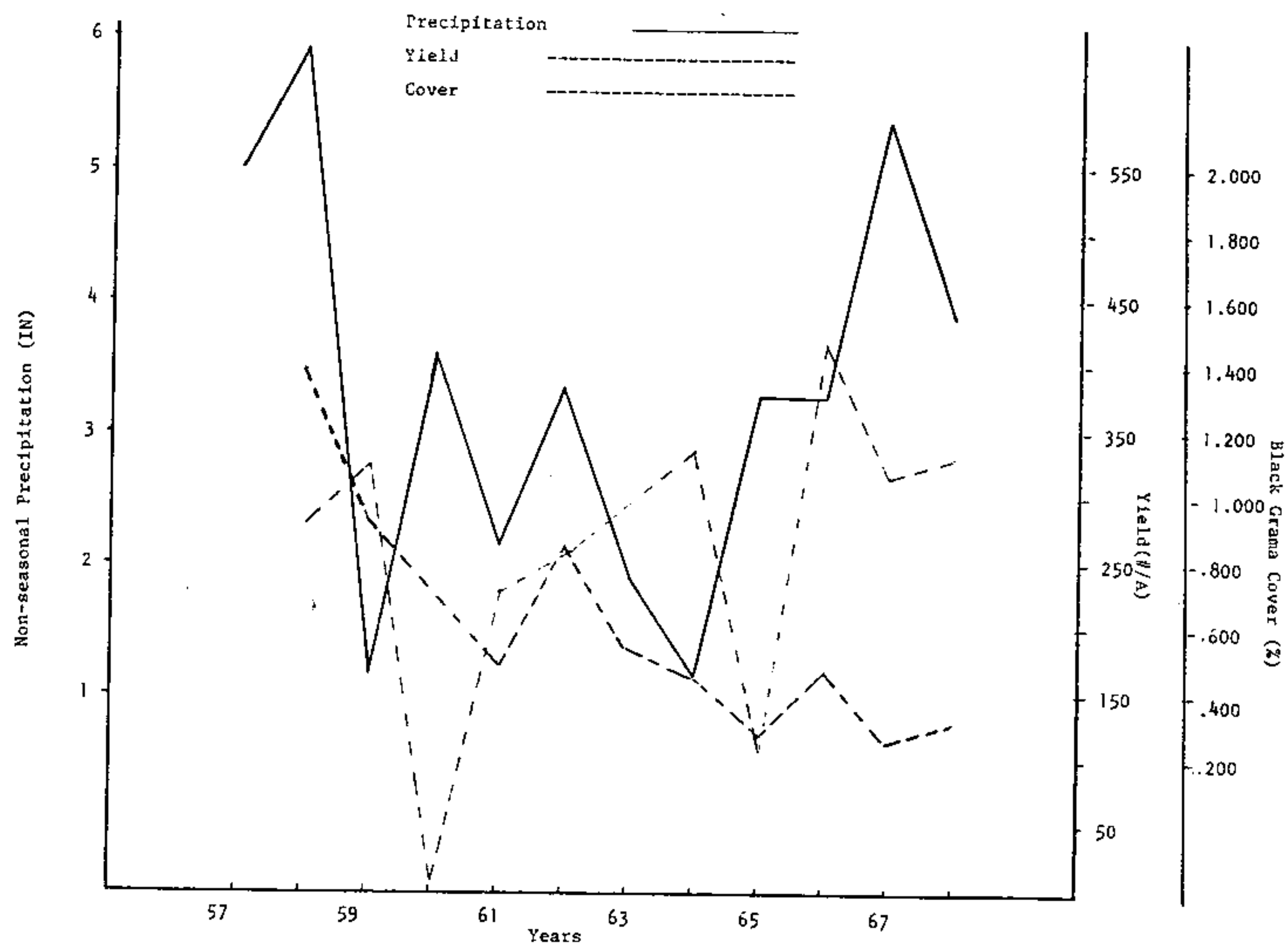


Figure 8. Black grama cover, perennial grass yield and nonseasonal precipitation for 1957-68 in good condition black grama in pasture 2.

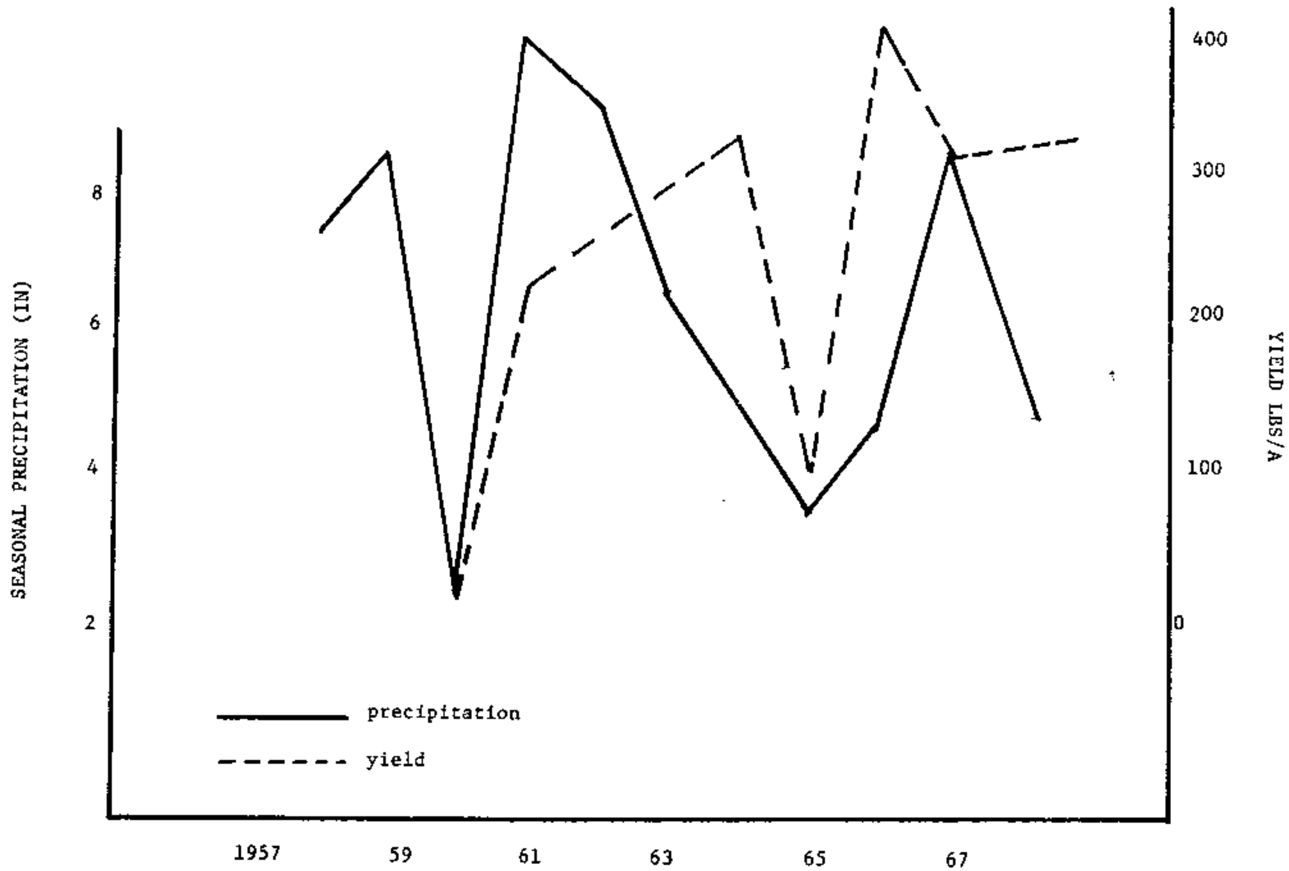


Figure 9. Perennial grass yield and seasonal precipitation for 1957-68 in good condition black grama area in Pasture 2.

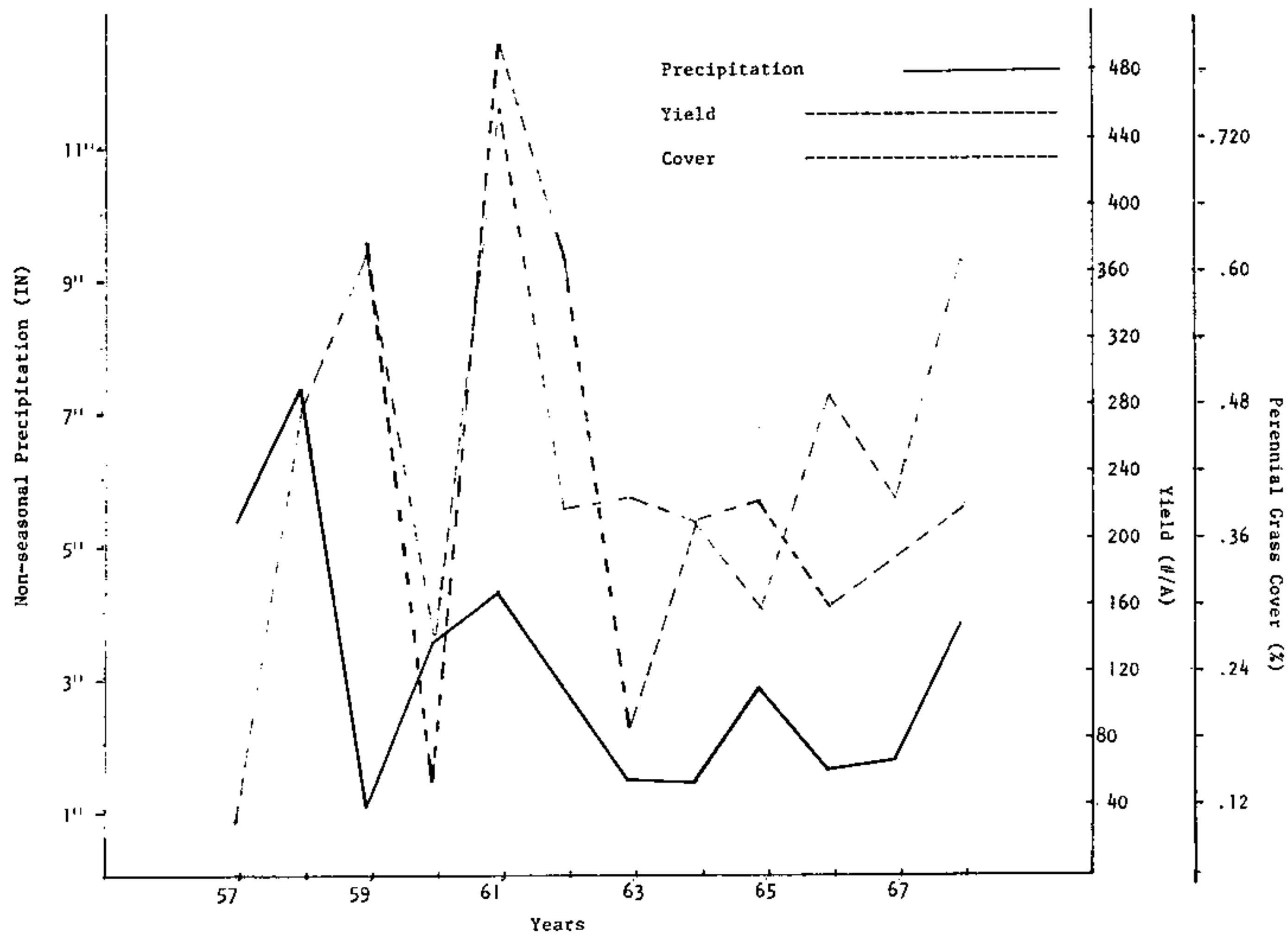


Figure 10. Perennial grass cover and yield and nonseasonal precipitation for 1957-68 in good condition black grama area in Exclosure B.

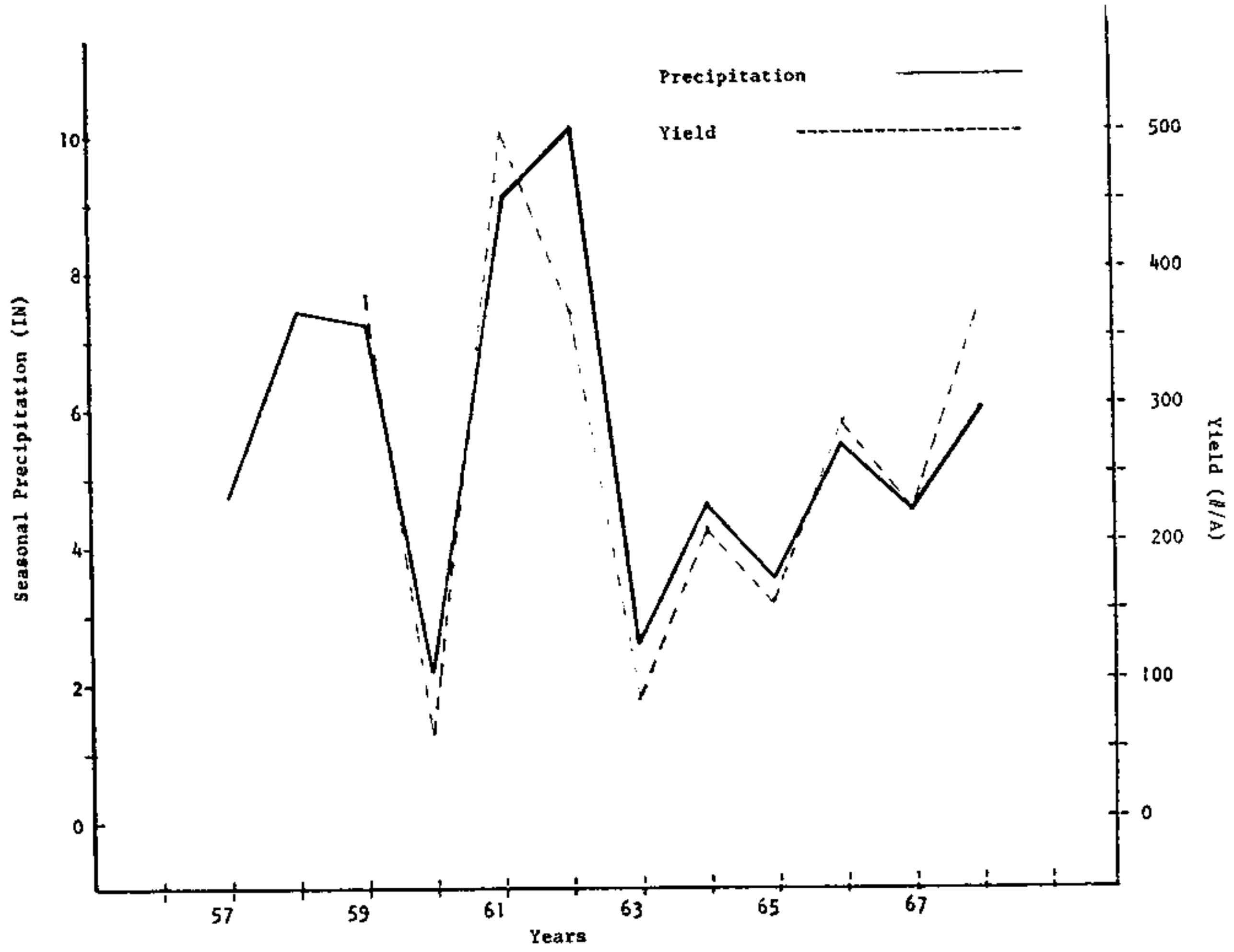


Figure 11. Perennial grass yield and seasonal precipitation for 1957-68 in good condition black grama area in Exclosure B.

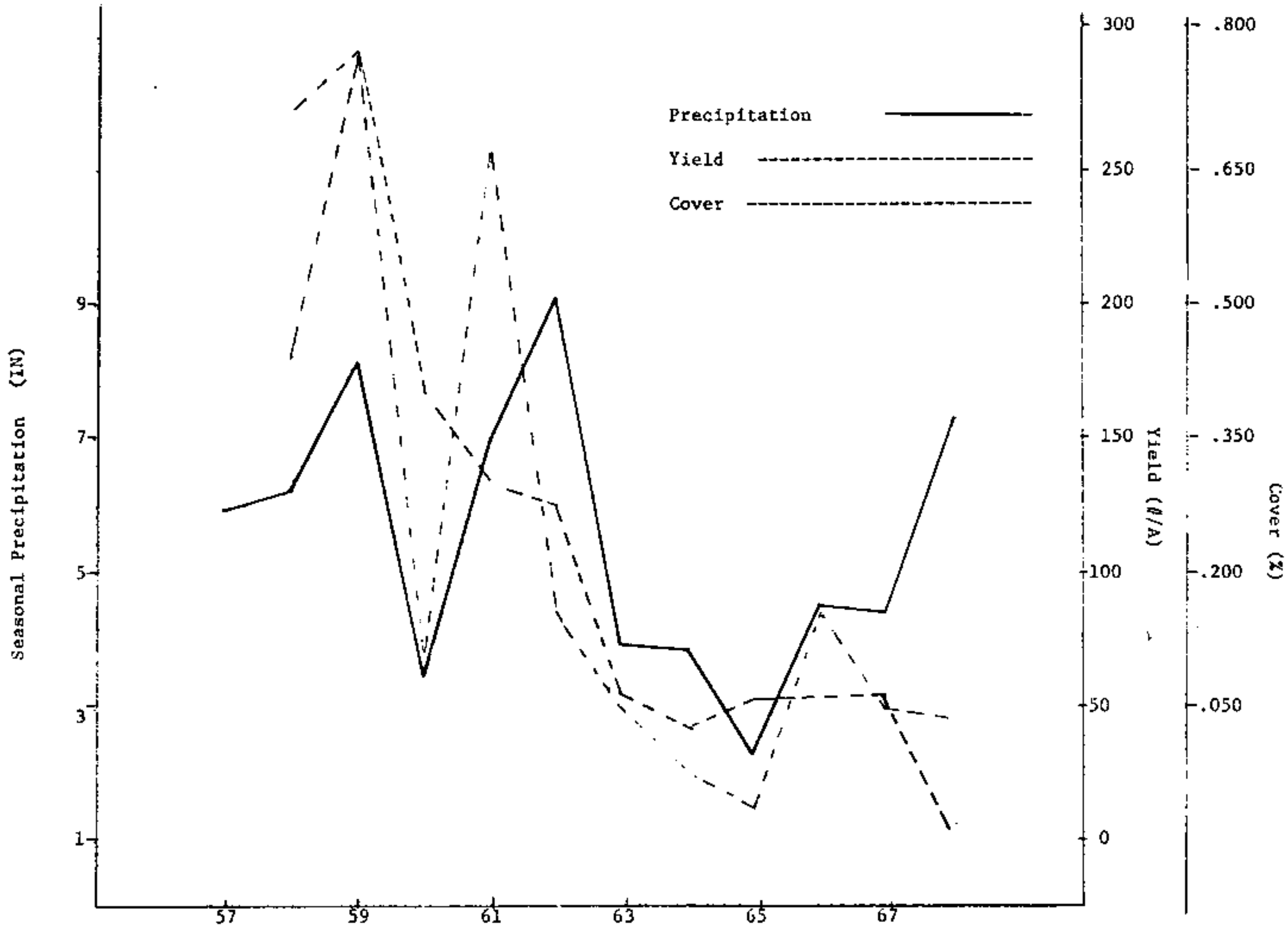


Figure 12. Perennial grass cover and yield and seasonal precipitation for 1957-68 in poor condition deep sand site in pasture.

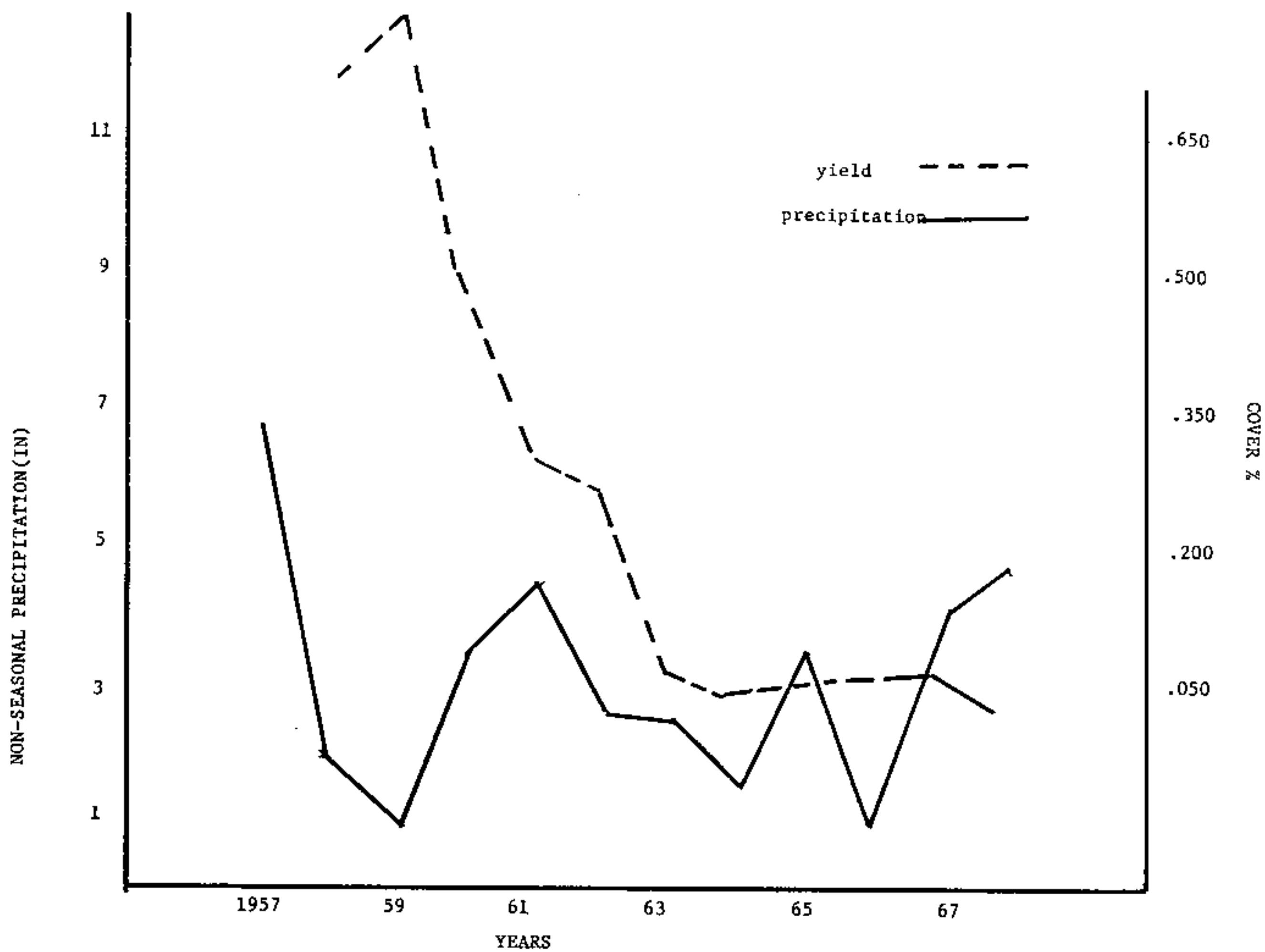


Figure 13. Perennial grass cover and nonseasonal precipitation for 1957-68 in poor condition deep sand site in pasture 11.

stand on the area. The exclosure north of Headquarters is an old lake bed and water remains there for short periods after run-in.

Figures 14 - 16 show the relationship between tobosa yield and seasonal precipitation at 3 locations. Figures 17 - 18 show the relationship between burrograss yield and seasonal precipitation at 2 location. Generally, there is a good relationship between seasonal precipitation and yield. Consideration of run-in would undoubtedly improve the relationship.

Estimates of Plant Growth

Yields of perennial grasses have been obtained at the close of the growing season since 1958 or 1959. Soil moisture estimates at those locations were also available. Using the soil moisture information and the total grass production for the year, we developed graphs showing the estimated production during the summer growing season at 4 locations (Fig. 19 - 22). For instance, if most of the summer's soil moisture was recorded July 10 - August 8, we showed most of the grass production for that period. The locations are: 1) a black grama-mesa dropseed area at Exclosure B; 2) a mesa dropseed area at Exclosure A; 3) a tobosa area at the south boundary; and 4) a burrograss area at the south boundary.

Life Characteristics

Canfield (1957) reported that some black grama plants lived as long as 14 years. A mean life span was not reported, but his data suggests a life span of approximately 2 years. Of the black grama plants we have studied the mean life span is 10.15 years (Table 8). Those plants definitely known to have been produced by stolens had a life span of 6.64 years as compared to the life span of those produced from

Table 8. Mean life span (years) of plants. Recorded by source (if known) and species.

Species	All Plants	Plants that lived more than 1 year
Grasses		
Alo	2.60	3.00
Ber (unknown source)	14.79	-
Ber (stolons)	6.64	-
Hmu	3.00	8.33
Mar	5.40	16.00
M. arenacea	2.60	4.91
Sai	10.33	15.00
Sbr (unknown source)	12.39	13.53
Sbr (stolons)	10.58	12.50
Sfl (unknown source)	4.54	10.82
Sfl (seedlings)	1.02	-
Forbs		
All inc	1.08	2.00
Bai mul	1.33	2.00
Cas bau	1.20	2.50
Cro cor	1.62	3.40
Eup alb	1.30	2.4
Evo pil	1.05	3.00
Les fen	1.28	2.73
Psi tag	1.23	2.50
Sol ela	1.71	3.73
Half-shrub		
Gut sar	2.27	3.77

Symbol	Scientific Name	Common Name
Alo	Aristida longiseta	Red three-awn
Ber	Bouteloua eriopoda	Black grama
Hmu	Hilaria mutica	Tobosa
Mar	Muhlenbergia arenicola	Sand muhly
M. arenacea	M. arenacea	Ear muhly
Sai	Sporobolus airodes	Alkali sacaton
Sbr	Scleropogon brevifolius	Burrograss
Sfl	Sporobolus flexuosus	Mesa dropseed
All inc	Allionia incarnata	Trailing allionia
Bai mul	Baileya multiradiata	Desert baileya
Cas bau	Cassia bauhimoides	Senna
Cro cor	Croton corymbulosus	Leather croton
Eup alb	Euphorbia albomarginata	Whitemargin euphorbia
Evo pil	Evolvulus pilosus	Evolvulus
Les fen	Lesquerella fendleri	Bladderpod
Psi tag	Psilostrophe tagetinae	Woolly paperflower
Sol ela	Solanum elaegnifolium	Silverleaf nightshade
Gut sar	Gutierrizea sarothrae	Broom snakeweed

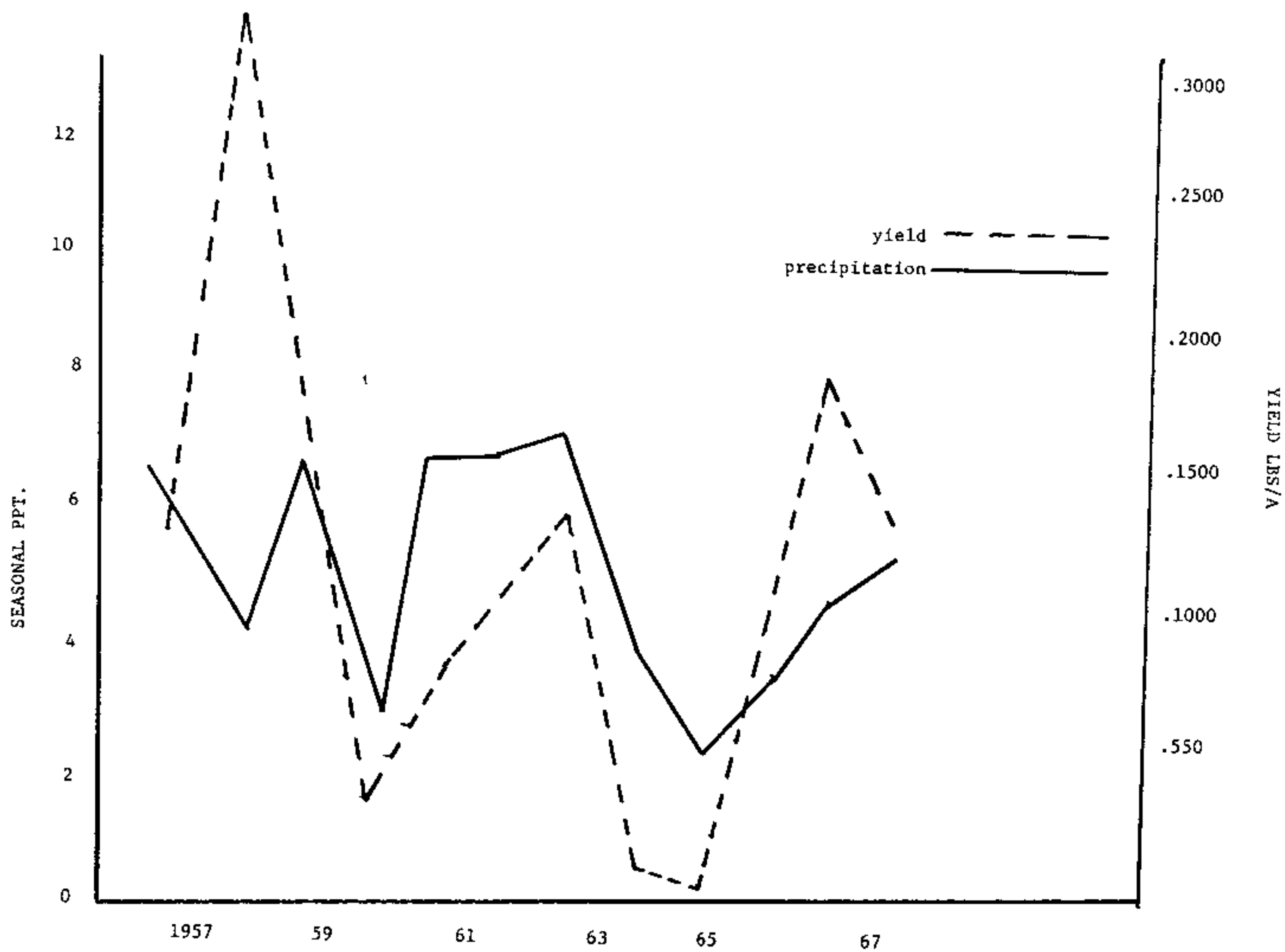


Figure 14. Tobosa yield and seasonal precipitation for 1957-68 and the exclosure at the south boundry.

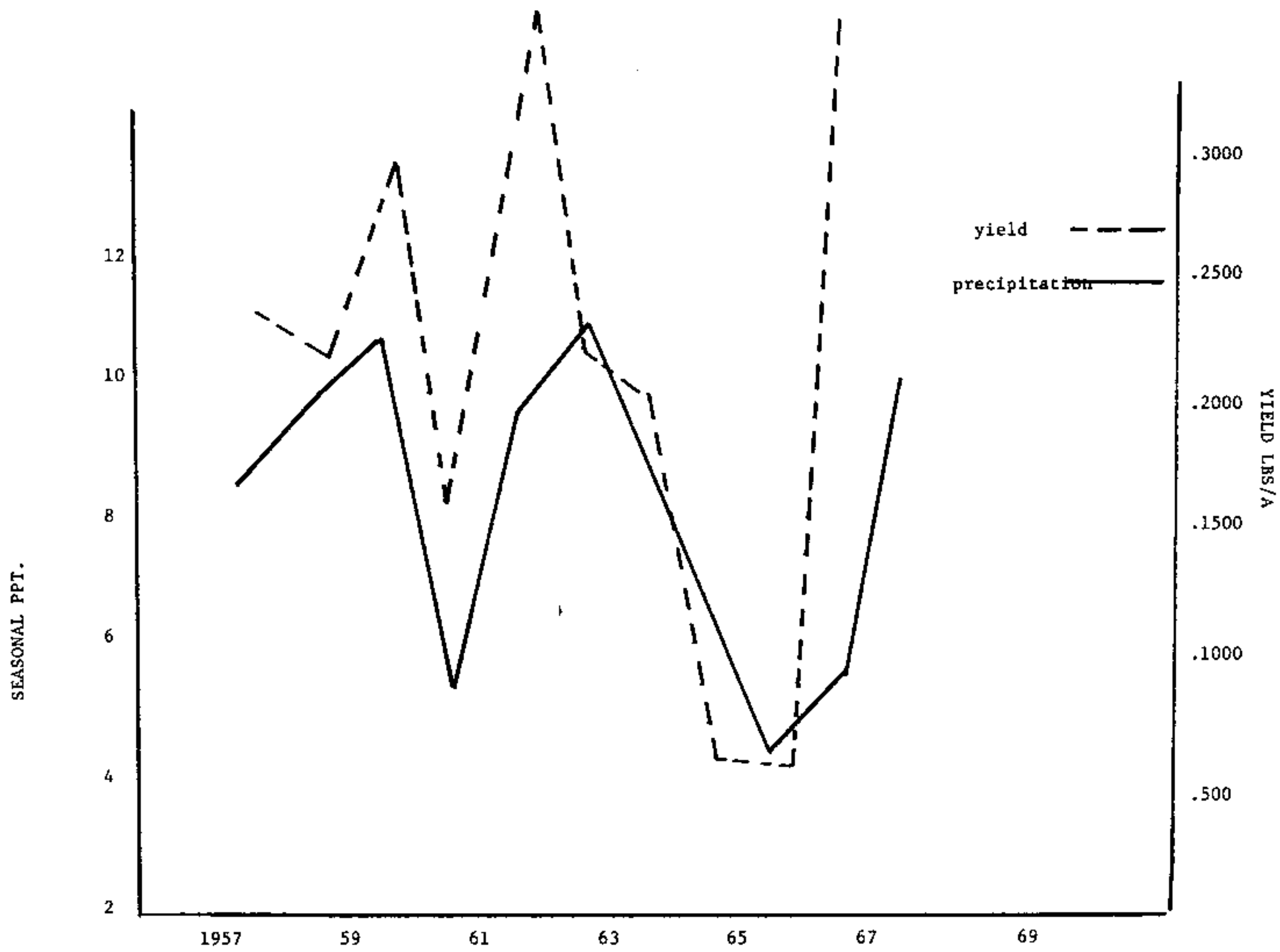
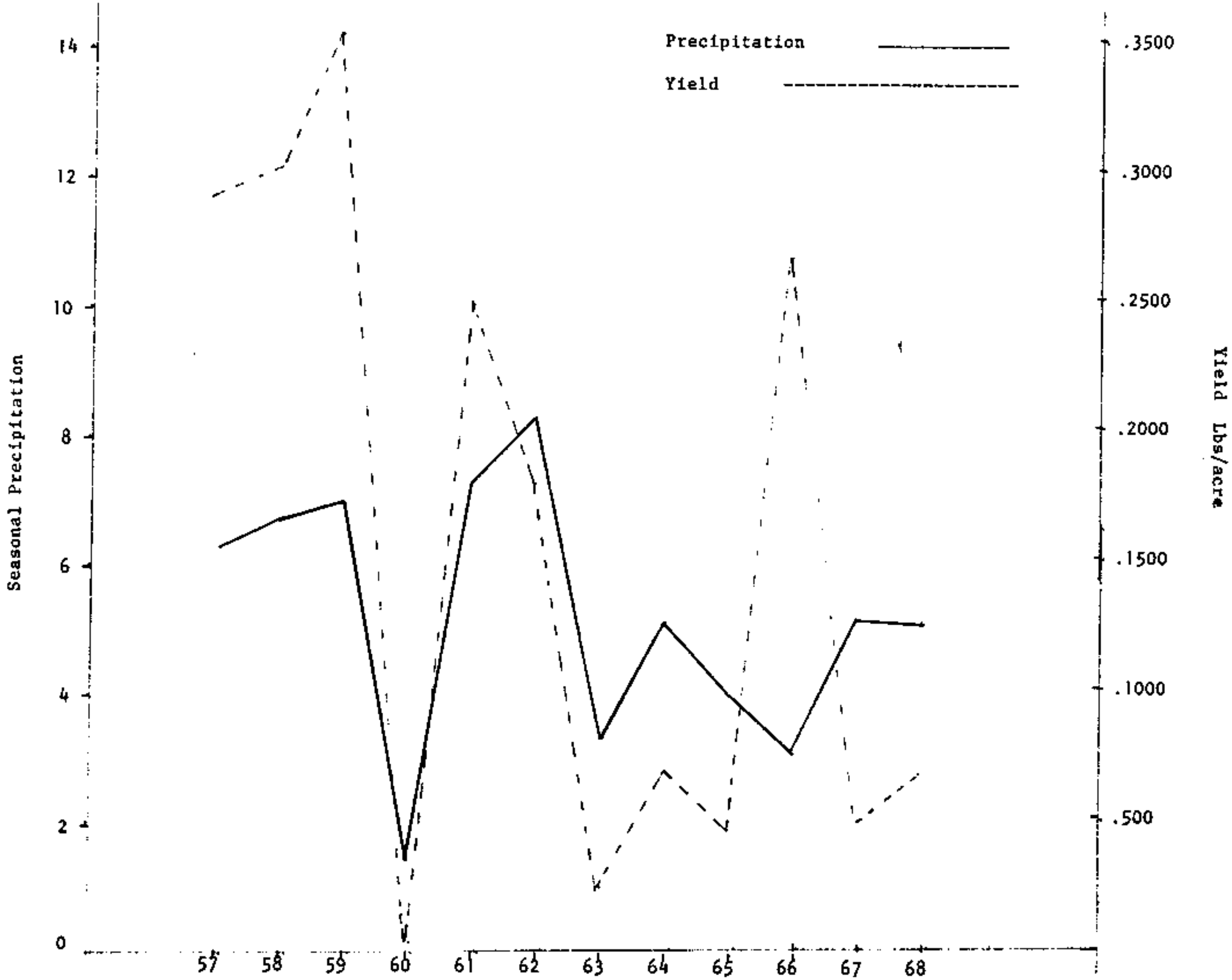


Figure 15. Tobosa yield and seasonal precipitation for 1957-68 at the fertilization study area.

Figure 16. Tobosa yield and seasonal precipitation for 1957-68 at the Exclosure north of Headquarters.



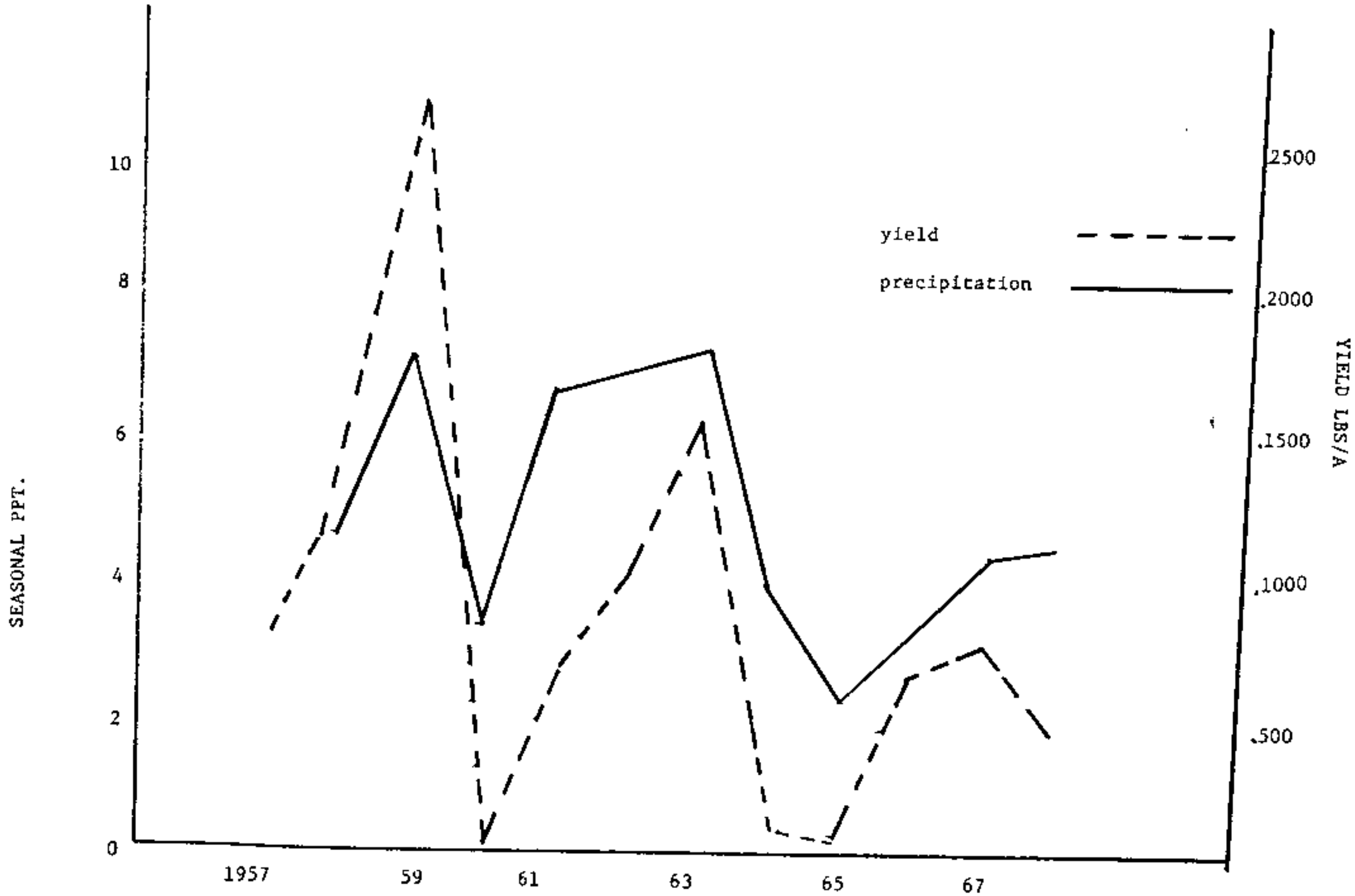


Figure 17. Burrograss yield and seasonal precipitation for 1957-68 at the exclosure at the south boundry.

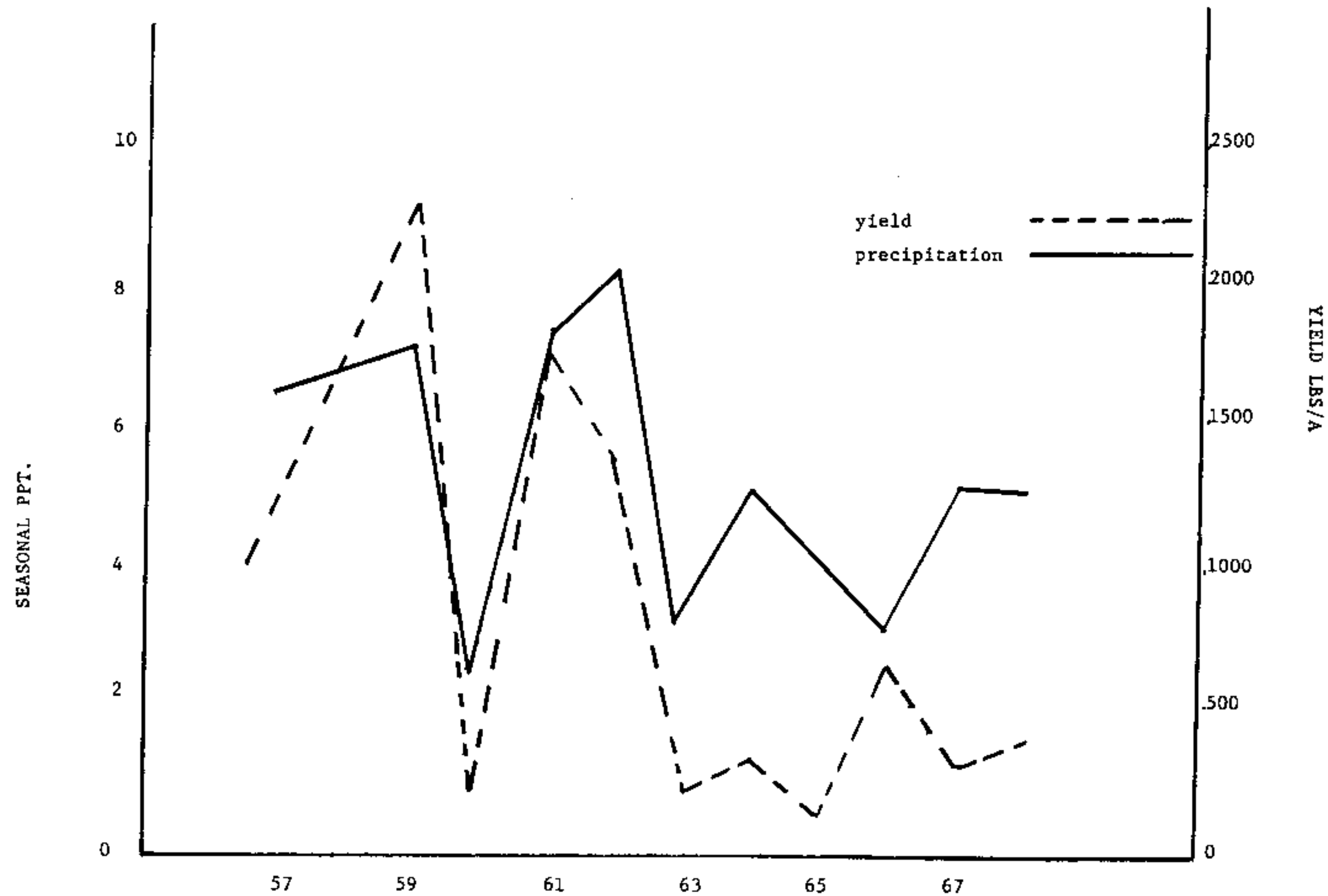


Figure 18. Burrograss yield and seasonal precipitation from 1957-1968 at the exclosure north of headquarters.

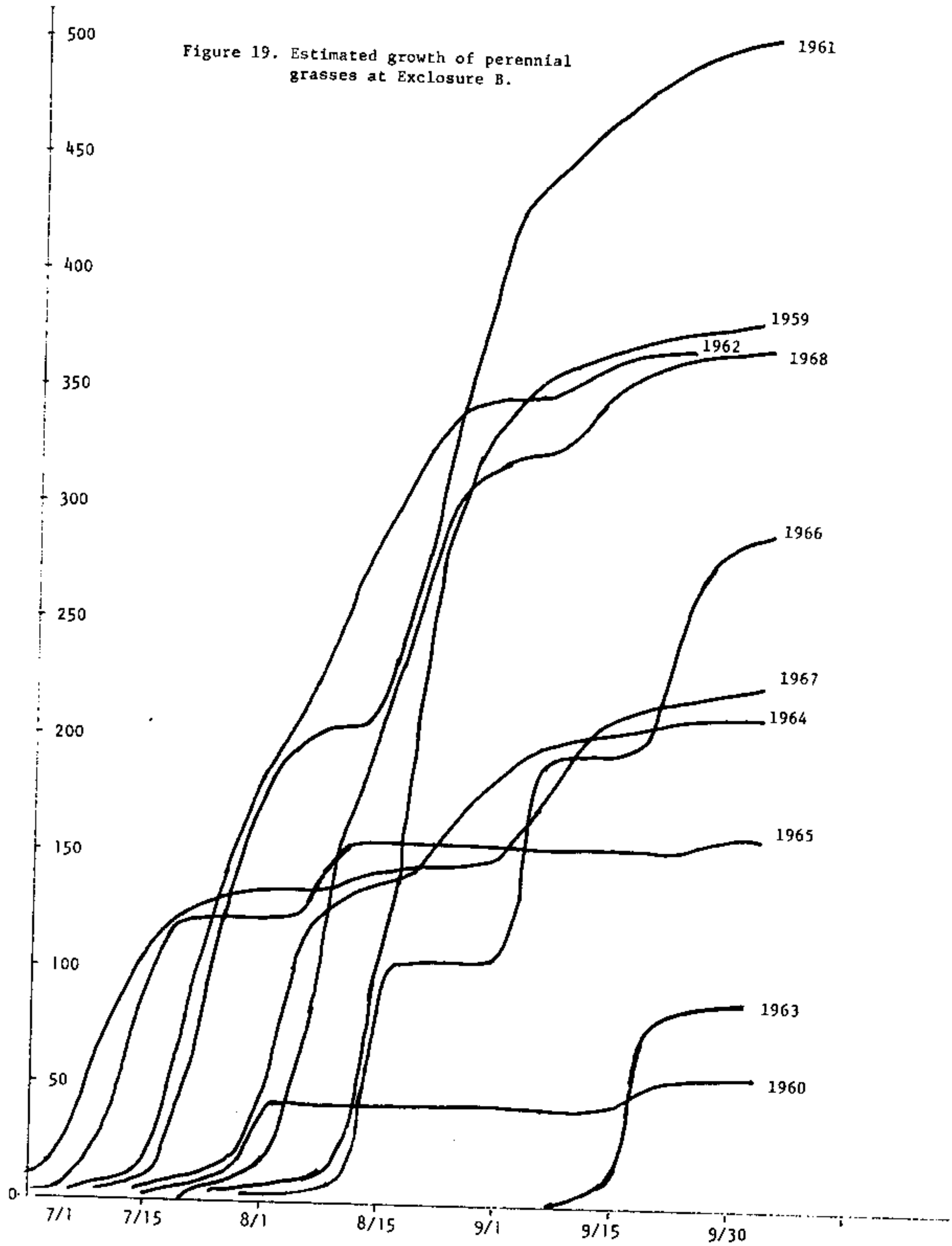


Figure 19. Estimated growth of perennial grasses at Exclosure B.

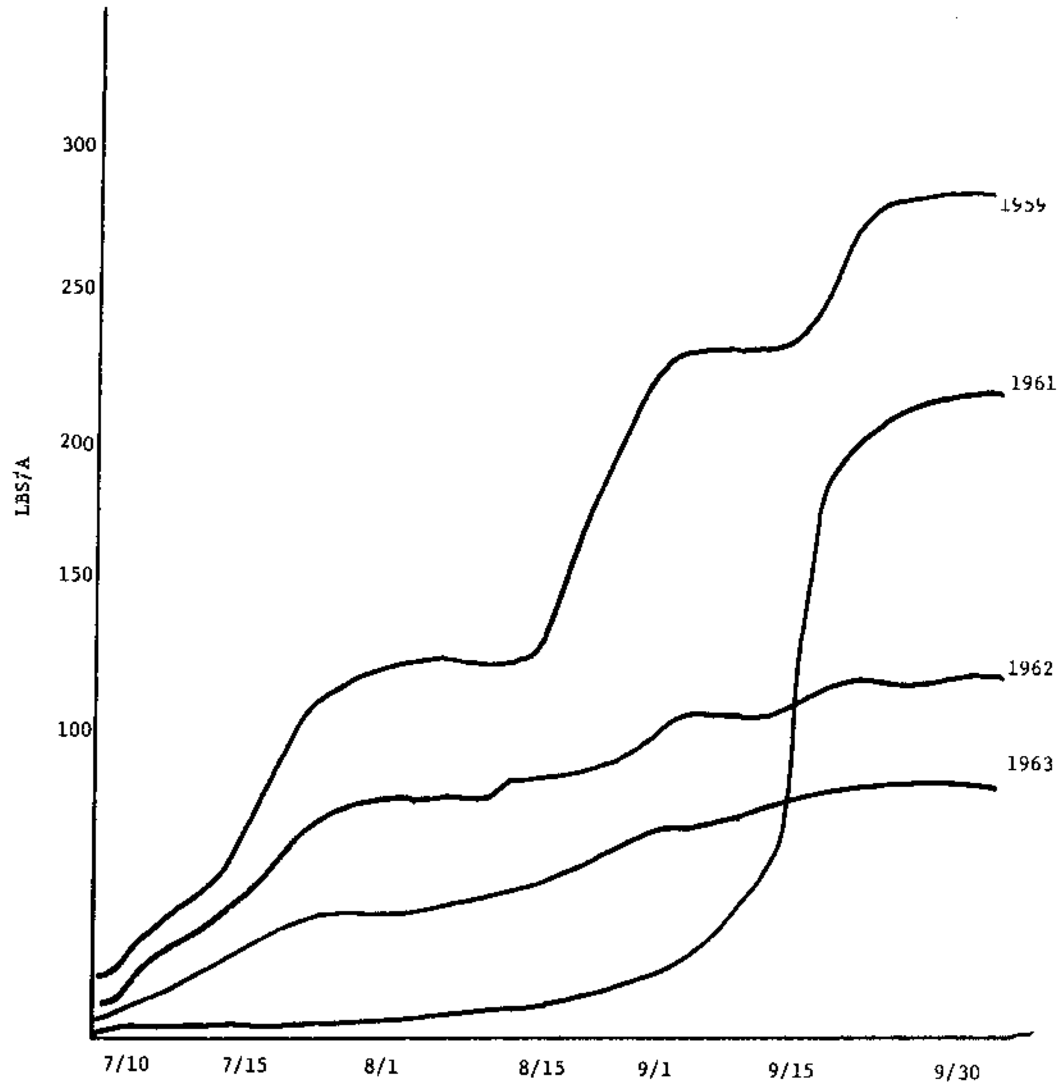


Figure 20. Estimated growth of perennial grasses at Exclosure A.

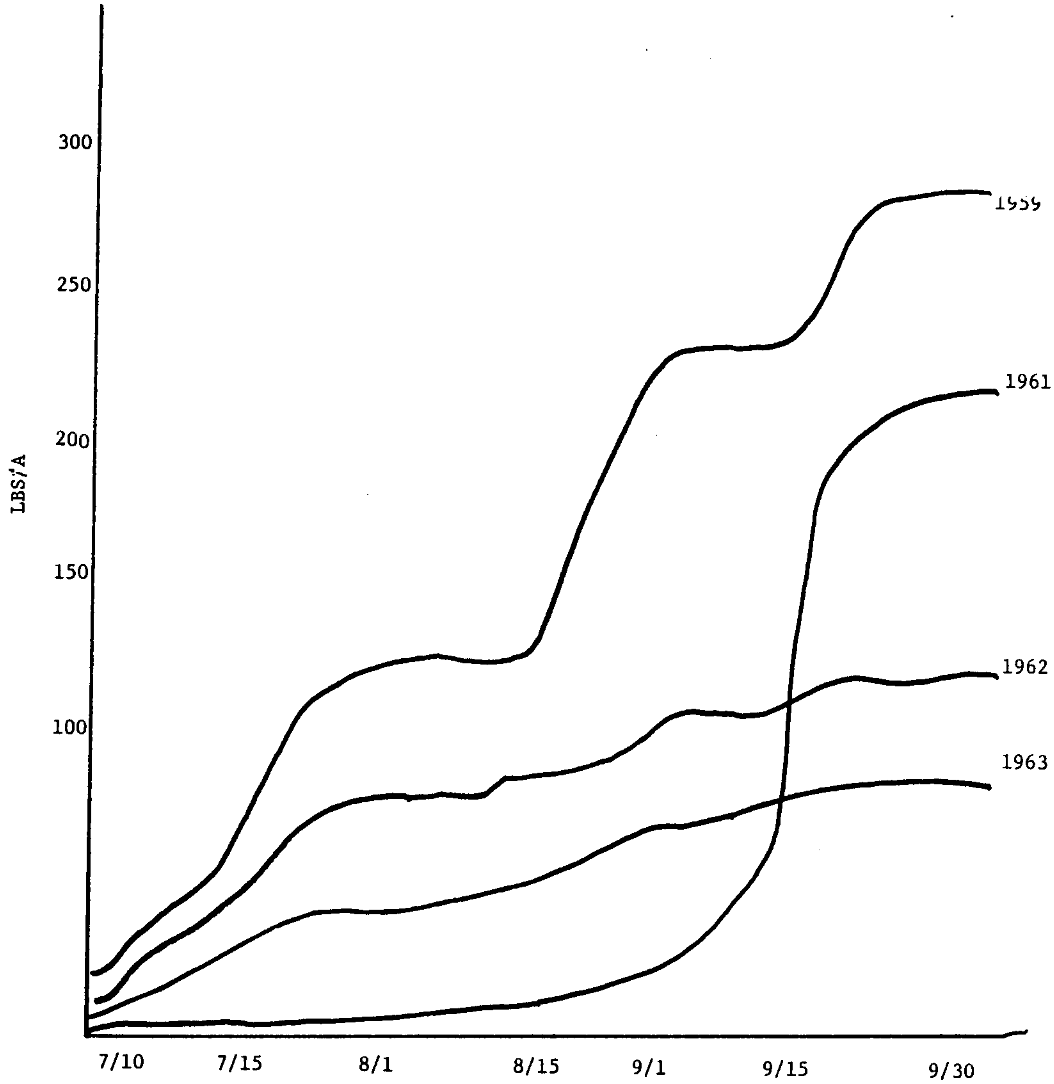


Figure 20. Estimated growth of perennial grasses at Exclosure A.

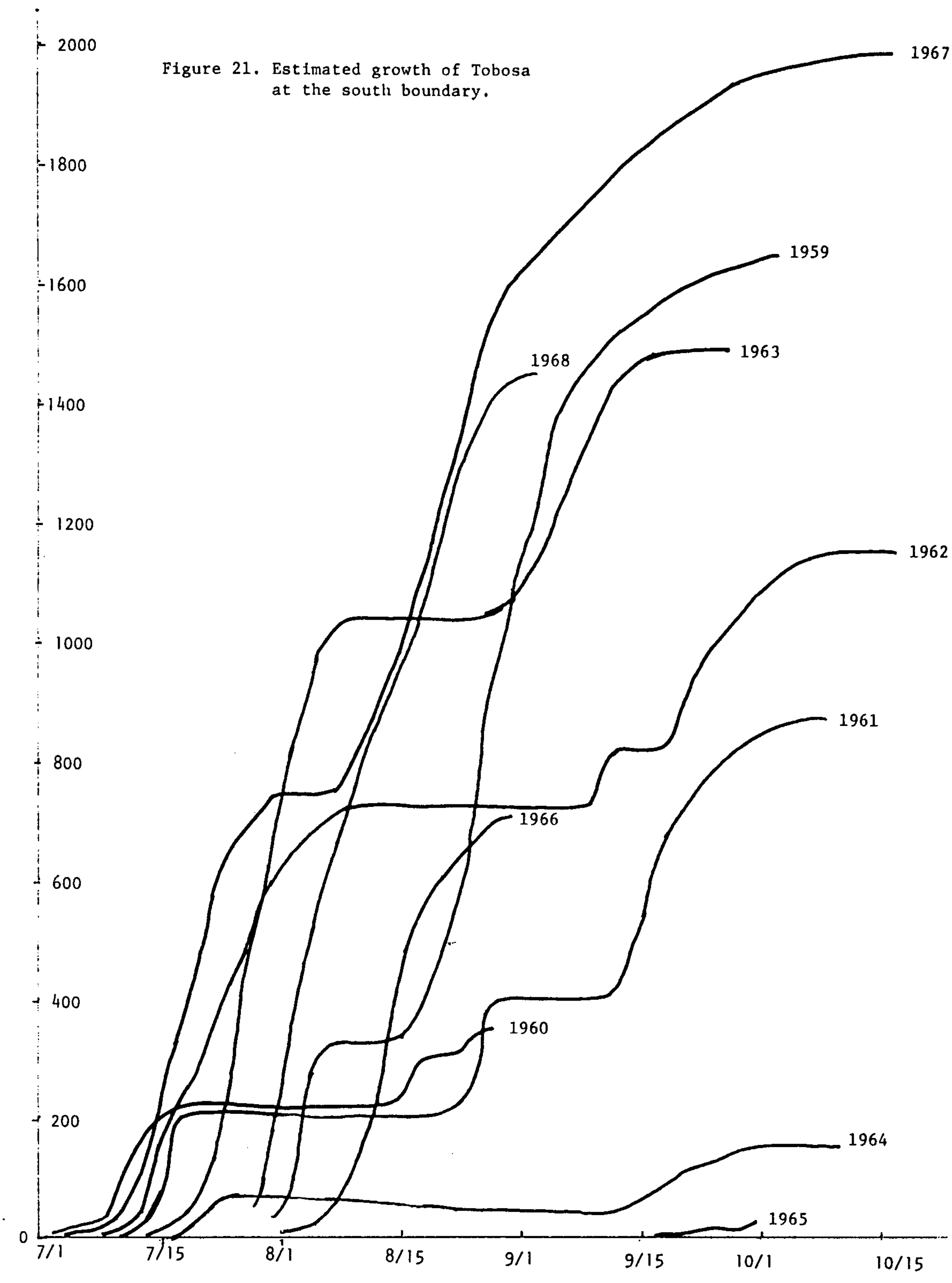


Figure 21. Estimated growth of Tobosa at the south boundary.

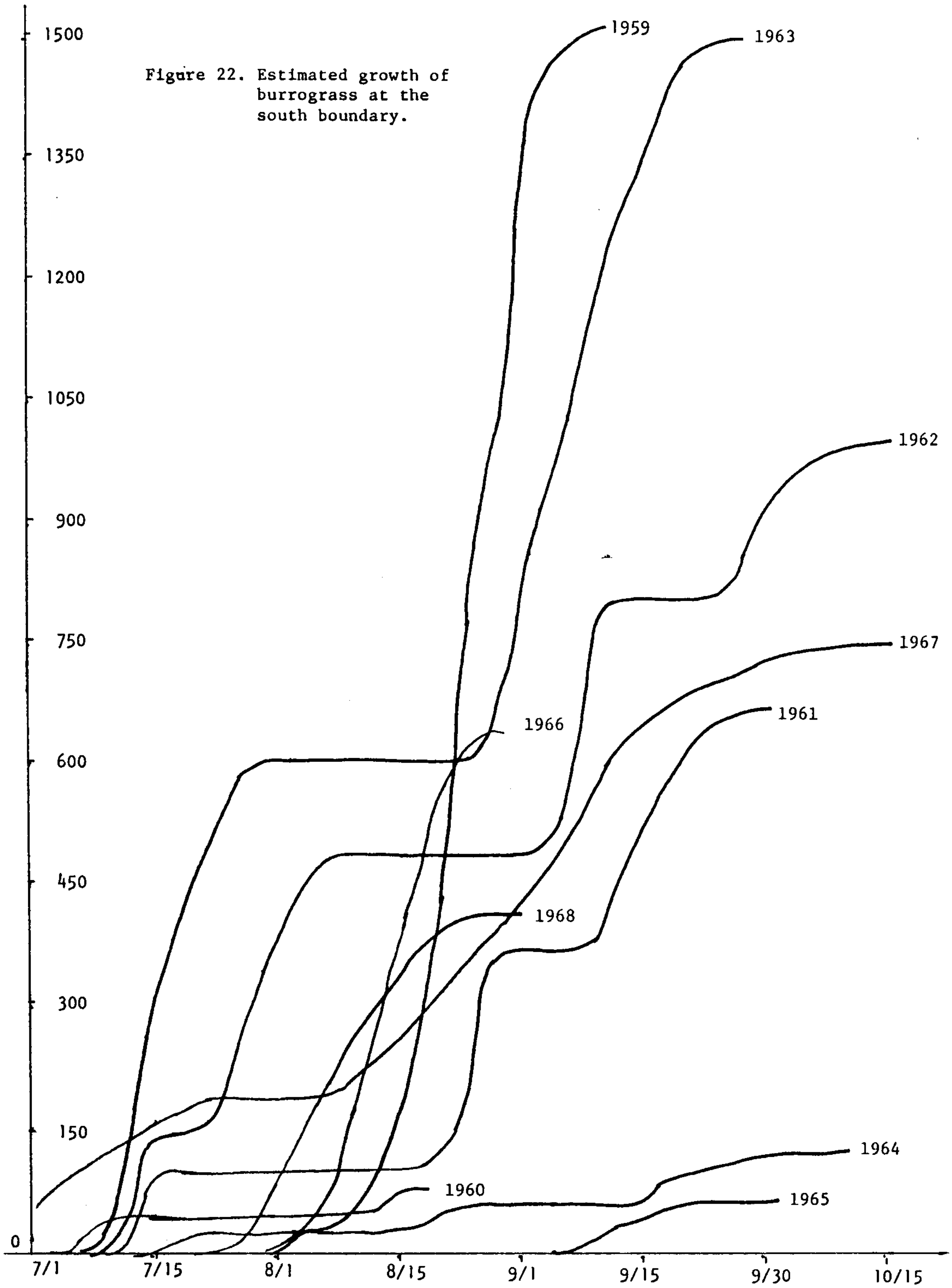


Figure 22. Estimated growth of burrograss at the south boundary.

unknown sources of 14.79 years. Eight plants lived longer than 25 years and 3 longer than 35 years (Table 9).

Table 9. Number of plants of each species that lived a given number of years.

Life of plant (years)	Grasses: Alo	Ber	Ber stolons	Hmu	Mar	M. arenacea	Sai	Sbr	Sbr stolons	Sfl	Sfl seedlings
1	6	1	11	8	7	14	2	1	3	32	196
2	-	2	2	-	4	3	1	5	1	7	3
3	-	3	2	-	2	3	-	1	1	3	-
4	-	1	1	-	-	1	1	2	1	2	-
5	-	1	2	-	1	-	-	1	1	1	-
6	1	6	-	-	-	2	-	3	-	1	-
7	2	3	1	1	-	-	-	4	-	1	-
8	-	3	1	-	-	-	-	-	2	-	-
9	-	-	-	2	-	1	-	-	-	1	-
10	-	1	2	-	-	-	-	1	-	-	-
11-15	-	1	3	-	5	1	-	5	1	5	-
16-20	-	3	5	-	1	-	-	4	-	4	-
21-25	-	7	1	-	-	-	1	1	-	1	-
26-30	-	4	-	-	-	-	-	1	-	1	-
31-35	-	1	-	-	-	-	1	1	-	-	-
36-40	-	3	-	-	-	-	-	1	1	-	-
41-45	-	-	-	-	-	-	-	-	1	-	-
46-50	-	-	-	-	-	-	-	1	-	-	-

Life of plant (years)	Forbs: All inc	Bai mul	Cas bau	Cro cor	Eup alb	Evo pil	Les fen	Psi tag	Sol ela	Half-shrubs: Gut sar
1	24	66	18	29	92	39	58	33	122	86
2	11	32	1	1	16	-	8	3	23	16
3	-	-	1	4	8	1	1	3	2	8
4	-	-	-	5	1	-	-	-	5	1
5	-	-	-	-	-	-	1	-	2	-
6	-	-	-	-	-	-	1	-	5	
7	-	-	-	-	-	-	-	-	-	
8	-	-	-	-	-	-	-	-	2	
9	-	-	-	-	-	-	-	-	-	
10	-	-	-	-	-	-	-	-	1	
11-15	-	-	-	-	-	-	-	-	1	
16-20	-	-	-	-	-	-	-	-	-	

See Table 8 for - Symbol, Scientific Name, and Common Name of grasses, forbs, and half-shrubs.

Tobosa had a mean life span of 3.00 years but those plants that lived more than 1 year had a life span of 8.33 years.

The mean life span of burrograss was 11.91 years with those plants of unknown sources having a life span of 12.39 years and those produced from stolons having a life span of 10.58 years.

Mesa dropseed had a mean life span of 1.84 years. Those plants from unknown sources had a life span of 4.54 years but if they survived the first year they had a life span of 10.82 years. Seedlings had a mean life span of 1.02 years and only 3 lived more than 1 year.

Desert baileya (Baileya multiradiata Harv. & Gray ex Torr.) had a mean life span of 1.33 years and none lived more than 2 years. A life span of 1.30 years was shown by whitemargin euphorbia (Euphorbia albomarginata Torr. & Gray) with 25 of 117 plants living more than 1 year. Silverleaf nightshade (Solanum elaeagnifolium Cav.) had a mean life span of 1.68 years with 41 of 161 plants living longer than 1 year and one living for 11 years.

The only shrub or half-shrub that has been studied enough to indicate a trend is broom snakeweed. This species has had a mean life span of 2.27 years, with 50 of 97 plants living longer than 1 year and 1 living 19 years.

We calculated life tables for those species with enough preliminary data to obtain fairly reliable estimates. The expectation of life, or mean life-time remaining to those attaining each age interval (years) is reported in Table 10. The expectation of life was calculated by:

Table 10. Expectation of life, or mean life-time remaining to those attaining age interval (years).

Age	Grasses			Forbs					Half-shrub
years	Ber	Sbr	Sfl	Bai mul	Cro cor	Eup alb	Les fen	Sol ela	Gut sar
0-1	7.24	7.05	1.54	.99	1.08	.80	.78	1.17	.82
1-2	6.89	6.87	8.51	.50	2.07	.88	1.28	2.17	.92
2-3	7.17	6.99	8.43	-	1.22	.56	2.37	3.29	.67
3-4	6.65	6.62	8.09	-	.49	.44	2.28	2.63	.50
4-5	6.25	6.04	7.42	-	-	-	1.28	2.59	-
5-6	5.49	5.68	6.74	-	-	-	.50	2.04	-
6-7	4.81	5.62	6.04	-	-	-	-	2.96	-
7-8	4.46	5.13	5.31	-	-	-	-	1.96	-
8-9	3.91	4.13	4.31	-	-	-	-	2.38	-
9-10	3.33	3.32	3.51	-	-	-	-	1.70	-
10-11	-	-	-	-	-	-	-	.57	-
10-15	2.33	4.26	2.51	-	-	-	-	-	-
15-20	1.85	3.99	2.19	-	-	-	-	-	-
20-25	1.49	3.42	1.85	-	-	-	-	-	-
25-30	1.37	2.83	.49	-	-	-	-	-	-
30-35	1.08	2.21	-	-	-	-	-	-	-
35-40	.63	2.03	-	-	-	-	-	-	-
40-45	-	1.52	-	-	-	-	-	-	-
45-50	-	1.09	-	-	-	-	-	-	-

Symbol	Scientific Name	Common Name
Grasses:		
Ber	Bouteloua eriopoda	Black grama
Sbr	Scleropogon brevifolius	Burrograss
Sfl	Sporobolus flexuosus	Mesa dropseed
Forbs:		
Bai mul	Baileya multiradiata	Desert Baileya
Cro cor	Croton corymbulosus	Leather croton
Eup alb	Euphorbia albommarginata	Whitemargin euphorbia
Les fen	Lesquerella fendleri	Bladderpod
Sol ela	Solanum elaegnifolium	Silverleaf nightshade
Half-shrub:		
Gut sar	Gutierrezia sarothrae	Broom snakeweed

(1) d_x = number dying in age interval out of 100 born,

(2) l_x = number living at beginning of age interval out of 100 born,

(3) $L_x = \frac{l_x + l_{(x+1)}}{2}$

(4) $e_x = \frac{L_{x(1)} + L_{x(2)} + \ldots L_{x(n)}}{l_{(x-1)}}$ = life expectancy.

Characteristics of establishment years varies with species and plant characteristics. Establishment of new black grama plants is largely through stolons and tillering. Few plants are established as seedlings because of the failure of seeds to mature satisfactorily and their low viability. Establishment is usually characterized by a favorable growing season which produces good stolon growth followed by another favorable year for rooting to take place at the nodes of the stolon. Sometimes this occurs over a 3-year period. Winter or annual precipitation seems to be as important after the initial good growing season as is good growing season precipitation. Nelson (1934) indicated that the 15-month period previous to establishment was the critical period. Generally the first 2-3 years following a drought have the best establishment.

Tobosa is possibly more drought tolerant than black grama. The best establishment seems to be the second year, sometimes the first year, following a favorable growth and seed production year. The establishment seems to require a month of the growing season to have more than 1 inch of precipitation.

Burrograss seems to have its best establishment in years with average or above average seasonal and annual precipitation following a year of below average seasonal precipitation. Mesa dropseed has better establishment in years with higher than average seasonal precipitation or a month of the growing season with higher than average precipitation. Fluffgrass (Tridens pulchellus (H.B.K.) Hitchc.) has similar requirements for good establishment years.

Annual grasses, annual forbs, and perennial forbs have their best establishment in years of above average seasonal and annual precipitation following a year of below average seasonal and annual precipitation. Years of better establishment are summarized in Table 11.

Table 11. Ranking of years from highest to lower by number of plants established that year (established from quadrat records). Listed by species and source.

Rank	Ber sets	Ber stolons	Ber seedlings	Hmu	Other Perennial grasses	Sbr sets	Sbr stolons
1	1934	1927	1917	1919	1919	1936	1949
2	1927	1939	1916	1933	1936	1935	1938
3	1936	1932	1935	1943	1930	1933	1926
4	1928	1926	1938	1923	1943	1931	1955
5	1937	1928	1927	1931	1918	1938	1931
6	1920	1920	1918	1918	1947	1920	1968
7	1932	1931	1936	1940	1921	1953	1936
8	1930	1929	-	1934	1926	1941	1945
9	1933	1938	-	1924	1933	1916	1937
10	1926	1930	-	1925	1931	1929	1951
11	1939	1944	-	1916	-	1917	1947
12	1931	1947	-	1930	-	1940	1927
13	1919	1936	-	-	-	-	1960
14	-	1937	-	-	-	-	1932
15	-	-	-	-	-	-	1944
16	-	-	-	-	-	-	1957

Rank	Sfl unknowns	Sfl seedlings	Tpu	Annual grasses	Perennial forbs	Annual forbs
1	1965	1937	1968	1924	1935	1968
2	1949	1935	1937	1922	1938	1935
3	1959	1936	1965	1923	1936	1936
4	1961	1966	1927	1928	1937	1937
5	1958	1922	1960	1920	1922	1938
6	1942	1938	1959	1921	1933	1927
7	1945	1917	1958	1927	1919	1922
8	1968	1916	1943	1934	1927	1924
9	1967	1959	1926	1916	1929	1919
10	1931	1949	1944	1968	1942	1929
11	1956	-	-	1919	1968	1923
12	1953	-	-	1926	1949	1926
13	1966	-	-	1938	1924	1925
14	-	-	-	1936	1925	1941
15	-	-	-	1943	1950	1949
16	-	-	-	1959	1941	1939

Symbol	Scientific Name	Common Name
Ber	Bouteloua eriopoda	Black grama
Hmu	Hilaria mutica	Tobosa
Sbr	Scleropogon brevifolius	Burrograss
Sfl	Sporobolus flexuosus	Mesa dropseed
Tpu	Tridens pulchellus	Fluffgrass

VEGETATION CHANGE

Effects of Drought on Vegetation

A vegetation survey, taken annually from 1941 through 1957, is the basis for a study of the drought of the early 1950's. Grass basal cover was estimated each autumn by 50-ft line-intercept transects. Yield estimates for each perennial grass species were obtained by clipping a 4-inch by 50-ft belt transect. Cover data reflect the previous year's growing conditions, while yield data are governed by stand and current year's growing conditions. For example, the first severe drought year was 1951 but this was not reflected in the cover estimates until 1952, but it was shown in the yield estimates of 1951.

There is a network of rain gauges associated with the vegetational observations. Each vegetation observation, taken in the same general area each year, was related to the nearest rain gauge. In 1951, the July through September rainfall averaged 1.1 inches at the several rain gauges; in 1952, it averaged 3.3 inches; in 1953, 1.5 inches; in 1954, 3.5 inches; in 1955, 3.7 inches; and in 1956, it averaged 2.5 inches. The average annual precipitation for the 1951-56 period was only 54% of the long-time average.

The vegetation data were placed into strata according to soil type. We will confine our discussion to the major upland sites. The deep sands are underlaid by claiche at depths ranging from 36 to 50 inches. The dominant soil type in this unit has been tentatively identified as Berino loamy sand. Sand flats have an indurated caliche layer at depths of 25 to 30 inches. This has been tentatively identified as Cacique loamy sand. Shallow sands are underlaid with caliche at depths of 10 to 18 inches. The major soil type in this stratum is Simona loamy sand.

The fluctuations of black grama basal cover for the period 1941-1951 is given in Table 12. The basal cover for the other perennial grasses on the same site, dropseeds and threeawns, averaged 0.26%. The dropseeds and threeawns cover dropped to 0.03% in 1952, increased to 0.33% in 1955, but dropped in 1956 to 0.09%. On the sand flats, black grama cover between 1941-51 averaged 0.94% (Table 12). Table 12 also shows the yearly decline in basal area for the period between 1952 and 1957. The dropseeds and threeawns averaged 0.19% basal cover prior to the drought. They decreased to 0% in 1952, 0.11% (1954), 0.25% (1955), 0.09% (1956), and 0.19% (1957).

On shallow sands, black grama cover for the 1941-51 period averaged 1.10% (Table 12). The period from 1952 to 1957 was marked by great oscillations in % cover (Table 12). These data agree fairly well with the rainfall data. The dropseeds and threeawns cover averaged 0.29% prior to the drought. In 1952 it decreased to 0.03%, then slowly increased until it was 0.42% in 1955, and then decreased again in 1956.

Table 12. Black grama and yield for three sandy sites.

	Deep sands	Sand flats	Shallow sands
Cover (%)			
1941-51	0.86	0.94	1.10
1952	0.29	0.33	0.24
1953	0.32	0.49	0.80
1954	0.01	0.25	0.34
1955	0.02	0.28	1.31
1956	0.02	0.19	0.15
1957	0.01	0.26	0.51
Yield (lb/a)			
1941-50	359	523	549
1951	148	186	262
1952	117	182	195
1953	76	152	232
1954	28	113	126
1955	12	64	135
1956	34	214	225
1957	31	137	248

On deep sands the pre-drought black grama yields averaged 359 lb of air-dry herbage per acre (Table 12). It continually decreased from 148 lb in 1951 to 12 lb/a in 1955. The yield for the other perennial grasses, the dropseeds and threeawns, averaged 112 lb/a before 1951. In 1951 yield dropped to a trace and then gradually increased to 72 lb/a in 1956.

On the sand flats, black grama yields for the 1941-50 period averaged 523 lb of air-dry herbage per acre. From 186 lb in 1951 it declined steadily until in 1955 the black grama yields were 64 lb/a. The dropseeds and threeawns yielded an average of 129 lb/a prior to the drought. In 1951 there was virtually no yield. After 1952 yield increased gradually until in 1955 it was 73 lb/a.

On shallow sands, black grama yields for the 1941-50 period averaged 549 lb/a. The yield fluc - uations from 1951-1956 are given in Table 12. The dropseeds and threeawns production on shallow sands averaged 160 lb/a prior to the drought. In 1951 it dropped to 11 lb/a and remained at that level for the remainder of the drought except for a slight increase in 1954 when it was 82 lb/a.

No stratum was favored by precipitation during the drought. Yet, effects on the vegetation were not the same over all sites. On deep sands the 1954-57 black grama cover was 1 - 2% of the pre-drought average. On sand flats the 1954-57 black grama cover was 26% of the pre-drought average and on the shallow sands it was 52% of the pre-drought average. There is a direct relationship between drought damage and depth of soil. The vegetation on the deeper soils sustained much greater damage. This seems reasonable when it is realized that grass plants obtain moisture more readily from the surface 12 inches of soil. On deeper soils the roots become more extended and thus more susceptible to drought damage during years when there is only enough moisture in the surface area. Probably the most important point is that the indurated caliche under these soils is almost impermeable and therefore holds moisture, even above field capacity, until the plant uses it. Therefore, on shallow soils moisture is held at a more readily obtainable depth. This moisture is not lost by evaporation through capillary movement because there is essentially no movement in these sands. On the deeper sands, the water-holding capacity of the subsoil is low and the moisture is more diffused throughout the profile.

The dropseeds and threeawns were even more susceptible to drought than black grama. In some of the strata essentially no plants were observed in the drought years. In the less severe drought years of 1954 and 1955, the dropseeds made a partial recovery from seedlings. These were subsequently reduced by the severe drought year of 1956. The threeawns were essentially eliminated by the drought. A discussion of the great drought would be incomplete without mention of the severe wind erosion as a result of drought damage to the perennial grasses. On the sandy soils, large areas left bare by the drought began to erode with the ever-present spring winds. The sand would drift until it reached fences, mesquite plants, buildings, or other obstacles. Many grass plants not killed by moisture stress were killed by this shifting sand.

We have been sampling selected areas within the three strata since 1958. On the deep sands a good stand of mesa dropseed developed in 1957. In 1958 and 1959 the mesa dropseed basal cover averaged 0.75%. In 1960, a drought year, it dropped to 0.5%. In 1961 and 1962, two years with considerably above-average rainfall, the dropseed cover continued to decrease - it averaged 0.3%. The following 4 droughty years, (1963-66), the dropseed cover dropped to 0.05%. The black grama cover increased slightly on the deep sands following two wet years; in 1959 it was 0.06% and in 1962 it was 0.07%. However, in the 1963-66 period it again decreased to 0.01 to 0.02%. Excluding droughty 1960, perennial grass yields, primarily mesa dropseed, averaged 235 lb/a during the 1958-61 period. Yield dropped to 86 lb/a in 1962 even though it was a very wet year. During the droughty years of 1963-66 perennial grass yields averaged 42 lb/a.

On sand flats black grama cover increased from 0.26% following the drought in 1957 to 0.5% in 1959. It dropped to 0.2% in droughty 1960, but recovered to 0.6% in 1961. Then it decreased to an average of 0.3% during the 1963-66 period. The dropseed cover on the medium-depth sand flats increased to 0.2% in 1959 and again to 0.3% in 1961. However, since then i decreased to 0.03% in 1966. The perennial grass produ tion on this site averaged 385 lb/a for the years 1959, 1961, and 1962. For the 1963-66 period it averaged 138 lb/a.

On shallow sands, black grama increased from 0.5% following the drought and averaged more than 1.0% in 1958 and 1959. It decreased to about 0.7% for 1960 an 1961 as a result of the severe drought from September, 1959 through November, 1960. Black grama cover increas ed in 1962 to 1.6% as a result of two very favorable growing seasons in 1961 and 1962. Then it decreased t an average of 0.46% for the drier years of 1963-66. The dropseeds and threeawns cover on the shallow sand site varied from 0.04 to 0.19% during the 1958-66 period. Perennial grass production for 1958 and 1959 averaged 340 lb/a, 111 lb/a in 1960, it averaged 470 lb/a in 1961 and 1962, and the drier 1963-66 period it averaged 272 lb/a.

Since 1950 we have experienced three severe drought periods. The first was the Great Drought of 1951 through 1956 which was perhaps a one in 500 year occurrence. The next was a very severe drought for a relatively short period - September, 1959 througl November, 1960. The third drought period, 1963-66, was not as severe as the 1951-56 drought but yet the vegetation was reduced to about the same levels.

On shallow sands, black grama cover was reduced to about 0.5% following the drought of 1951-56 and again during the 1963-66 drought. On sand flats black grama cover was reduced to about 0.25% during both drought periods.

On deep sands, black grama was virtually eliminated by the 1951-56 drought but there was a slight improvement during the wetter years of 1957-59 and 1961-62. On this site there was a rapid increase of mesa dropseed in 1957. Basal cover remained at about 0.75% through 1959, then began declining until it was at a very low level from 1963 to 1966. It appears now that it will be many years before black grama again begins to dominate this site. We will likely have some dropseed, particularly during wetter years, but production from year to year will fluctuate greatly. Consequently, stocking on this site must be at a new and lower level than prior to the drought of the early 1950's. We must have a crop of dropseed seedlings established every 3 or 4 years to maintain a satisfactory stand. At this time it seems unlikely that we will have the proper combination of environmental factors for seedling establishment that often.

On sand flats black grama will recover after a few average or above-average rainfall years. It had reached about 0.5% in 1959 and again in 1961. From that point to an excellent cover of 0.8 to 1.0% would have required only 3 or 4 more favorable years.

On shallow sands, black grama cover had fully recovered from the 1951-56 drought by 1958. It will probably recover from the 1963-66 drought in 2 or 3 favorable growing seasons.

<u>Analysis of Factors Responsible for Vegetation Changes</u>

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 (Buffington and Herbel 1965).

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 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 the study 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 tne 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 ANIMAL FACTOR

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 change 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, i appears that mesquite was present in a scattered stand; 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 grasslanc 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 dominant. 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.

Livestock - Vegetation Interactions

We selected pastures 5 and 9 to examine stocking-forage crop-weather relations. Roughly half of pasture 5 is now in the mesquite sand dune type. A small area of about 100 acres is in the tobosa-burrograss type and the balance is fair condition black grama range. Since the drought of the 1950's, the forage crop has been at a lower level than prior to the drought (Fig. 23). This is reflected in the stocking. Both drought and the rapid increase of mesquite have contributed to the reduced stocking of pasture 5.

About half of pasture 9 is good to excellent condition black grama range. The forage crop is somewhat lower than prior to the drought but stocking has been about the same since 1960 as before 1952 (Fig. 24).

Figure 25 (Paulsen 1955) shows the surface acre requirements per animal unit on six pastures of the Jornada Range. Pasture 2, which shows an increasingly rapid rate of decline in grazing capacity, was mapped as having 65% of its area covered by mesquite in 1928. Based upon studies here and in other areas the pattern of mesquite invasion and thickening is one of ever increasing intensity. Thus the change in grazing capacity in pasture 2 was generally slow during the early years of record and much more rapid in recent years. The grazing use of pasture 2 has been conservative and predominantly in the winter-spring season when the grasses are dormant. Therefore, the invasion and duning by mesquite is largely responsible for the loss in grazing capacity.

Past records show that grazing capacity on black grama ranges can be expected to recover from drought under careful stocking and wise management. On the brush ranges the gradual loss in capacity can be expected to continue until brush control or some other range improvement measures are undertaken.

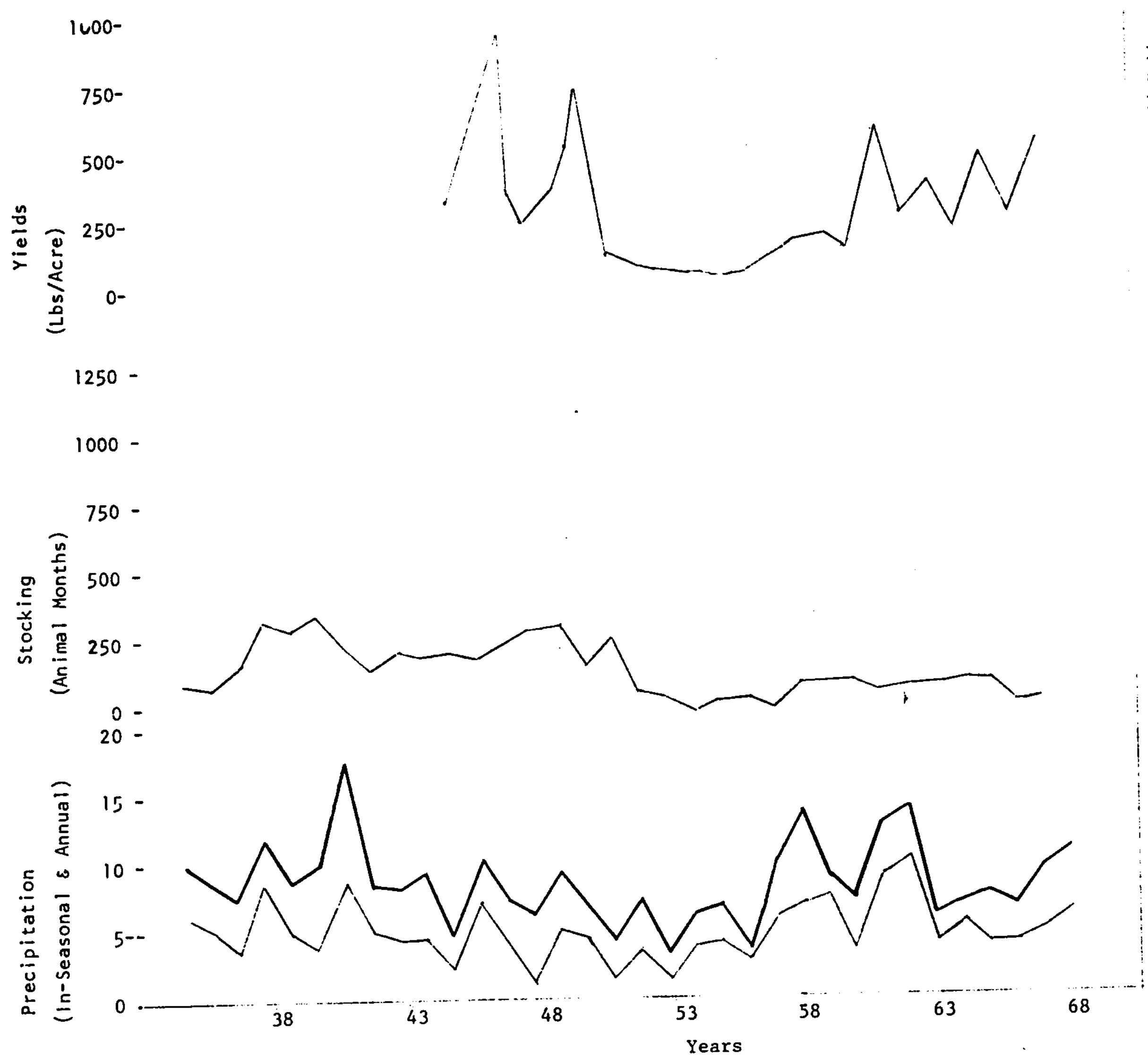


Figure 23.

Perennial grass yields stockings and precipitation in pasture 8.

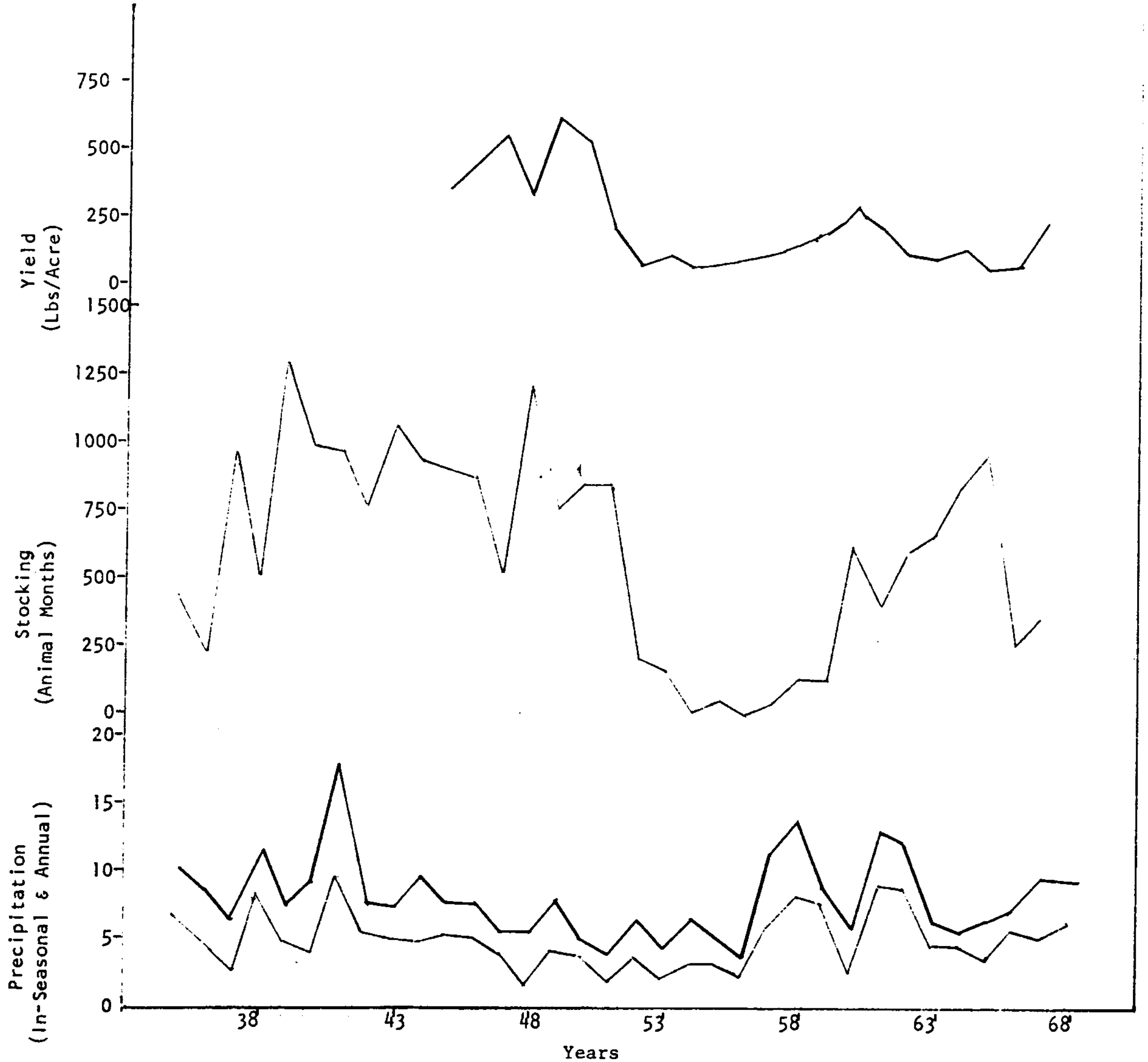


Figure 24.

Perennial grass yields, stockings and precipitation in pasture 9.

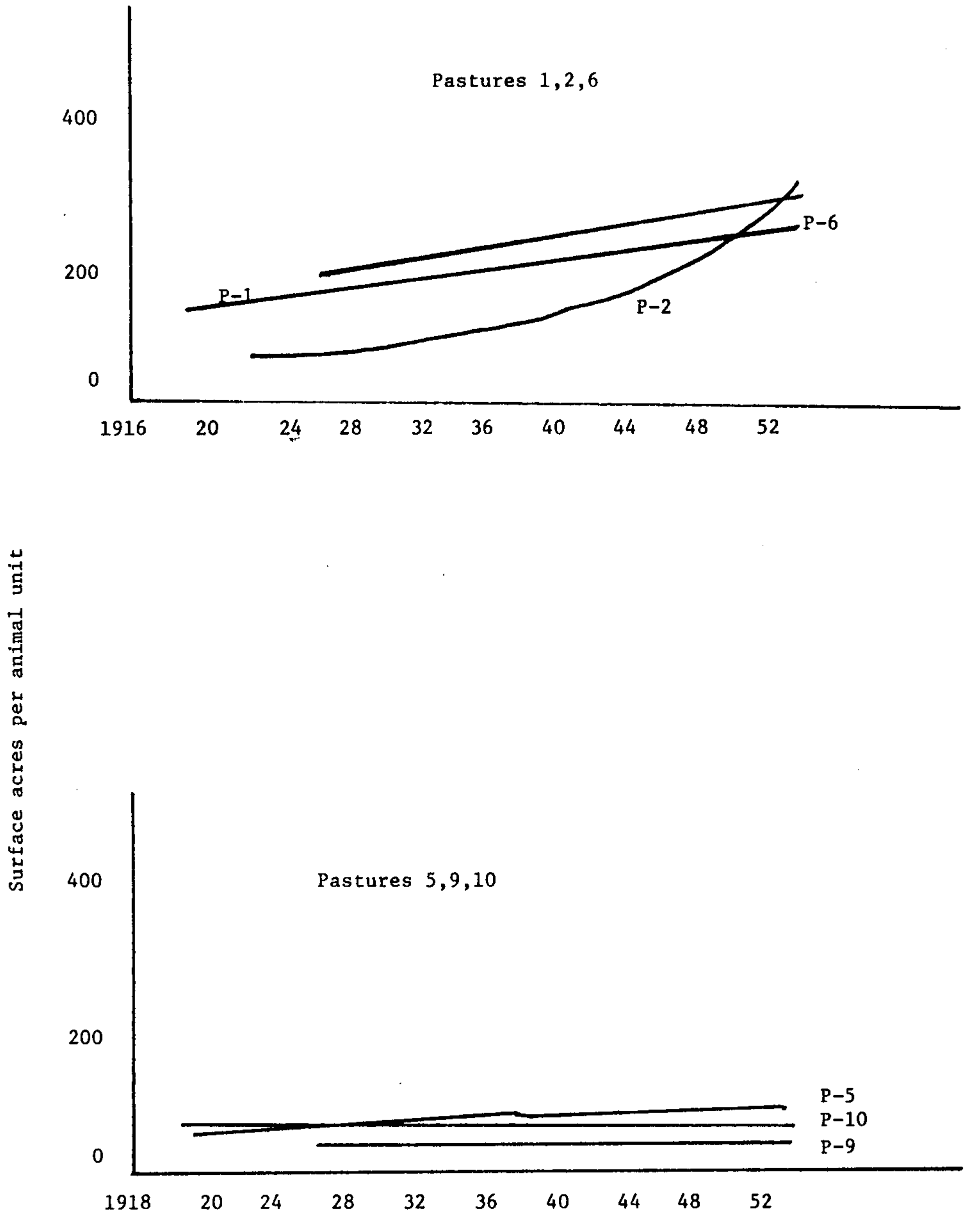


Figure 25. Surface acre requirements per animal unit on six experimental pastures, Jornada Experimental Range, 1916-53.

Table 13 shows vegetation cover in pasture 2 of the Jornada Range and an adjacent area off the Jornada more heavily stocked, as reported by Jardine and Hurtt (1917). They suggested that lighter summer use by livestock was responsible for the greater cover of "good" forage plants in pasture 2.

Table 13. Density of vegetation on range outside the Jornada compared to Pasture 2 of the Jornada. Outside range grazed at full-overflowing grazing capacity year-round. Pasture 2 grazed at 50% 3-4 months of growing season and at 80% of grazing capacity for the rest of the year. Recorded as cm^2 on 10,000 cm^2 quadrats (from Jardine and Hurtt, 1917).

Distance from water: (miles)	All Vegetation: Pasture 2	All Vegetation: Outside Range	Good Forage: Pasture 2	Good Forage: Outside Range	Medium Forage: Pasture 2	Medium Forage: Outside Range
.5	506	138	325	0	178	138
1.0	484	345	445	148	32	196
1.5	556	213	517	117	38	94
2.0	497	322	481	168	14	145
2.5	567	340	511	268	54	70
3.0	517	428	481	222	21	101
3.5	529	375	487	208	41	165
4.0	-	477	-	351	-	120
5.0	-	549	-	516	-	18

Livestock - Wildlife Relationships

The most important livestock and wildlife relationships on the area are mainly one of competition for food. Although there are predators on the area, only two species, the coyote and the bobcat, are large enough to prey on livestock; and then, only the very young animals may fall prey to predation. In addition, there has been a very strong predator control program on the area for many years. Therefore, the remainder of interaction is between livestock and other herbivores.

Engelking (1969) estimates the antelope herd at 56 animals. He lists the following plants of their diet in decreasing order; yucca, mesquite fruits, Acanthochiton wrightii (Torr.), bush muhly, sand muhly (Muhlenbergia arenicola Buckl.), and unidentified forbs. From the standpoint of their small numbers on the area and from the standpoint of their diet, it is safe to say that antelope compete very little with livestock on the Jornada. The above statements can probably be projected to also include mule deer on the area.

The major effect on vegetation, and therefore, the major factor in livestock-wildlife relationships is by rodents and rabbits. Figure 26 shows the number of jackrabbits and cottontail per section on the Jornada and adjacent College Ranch. Data on jackrabbit and cottontail populations (Figure 26) were collected by driving automobile trend routes. The density estimates were obtained by counting all rabbits that occurred within a 25 ft belt on either side, from the center of a non-graded ranch road. This resulted in 6 acres per mile being censused. These figures were then converted to rabbits per section. Caution must be exercised in relating vegetation and animal populations, because many animals cycle independent of available vegetation. Rabbits usually follow a cycle of 9-11 years, and rodents a 3-4 year cycle (Odum 1959).

Wood (1969) states that rodents on the nearby New Mexico State University Ranch consumed 7,915 lbs of vegetation per section per year. They stored another 5,824 lbs of plant material per section, per year. Because of the pulverized nature of food found in rodent's stomachs, identification of plant species could not be determined. However, analysis of the stored material in kangaroo rat dens, the most abundant species, showed: perennial grasses 18%, annual grasses 23%, snakeweed 43%, and pepper grass (Lepidium sp.) 7%. The remaining 9% was made up of seventeen other plants or plant categories. Vorhies and Taylor (1922) found that the six most important grasses on the Santa Rita Range comprised 85.6% of the material stored in kangaroo rat dens. These six species in decreasing order of stored weights were: rothrock grama (Bouteloua rothrockii Vasey), poverty threeawn (Aristida divaricata Humb. & Bonpl. ex Willd.), needle grama (Aristidoides (H.B.K.) Griseb.), purple grama (B. radicosa (Fourn.) Griffiths), sixweeks threeawn (A. adscensionis L.), spidergrass (A. Ternipes Cav.). In the spring and summer succulent portions of grasses were stored. However, the bulk of the storage consisted of air dried seeds.

Although, Wood (1969) found that the overall impact of rodents was greatest in the mixed mesquite and fourwing saltbush type, the effect on a very good black grama area was still great. In this area alone he found that denuding of vegetation by kangaroo rats around their dens took 10.6% of the area out of grass production. This denuding plus that amount eaten by kangaroo rats and other species of rodents has an important impact on desirable vegetation even on range that is in very good condition.

No data on rabbit diets were available for the study, but Currie and Goodwin (1966) found that jackrabbits in Utah grazed heavily on grasses during the spring and summer. By June more than 50% of the current growth of squirreltail (Sitanion hiptrix (Nutt.) J. G. Smith), needle-and-thread (Stipa comata Trin. & Rupr.), and indian ricegrass (Oryzopsis hymenoides (Rpm. & Schult.) Ricker) had been used. From July until the leaves dried in late September, all green growth of these grasses was constantly grazed. By using penned rabbits they determined that 5.8 jackrabbits consumed or wasted enough forage to feed one sheep.

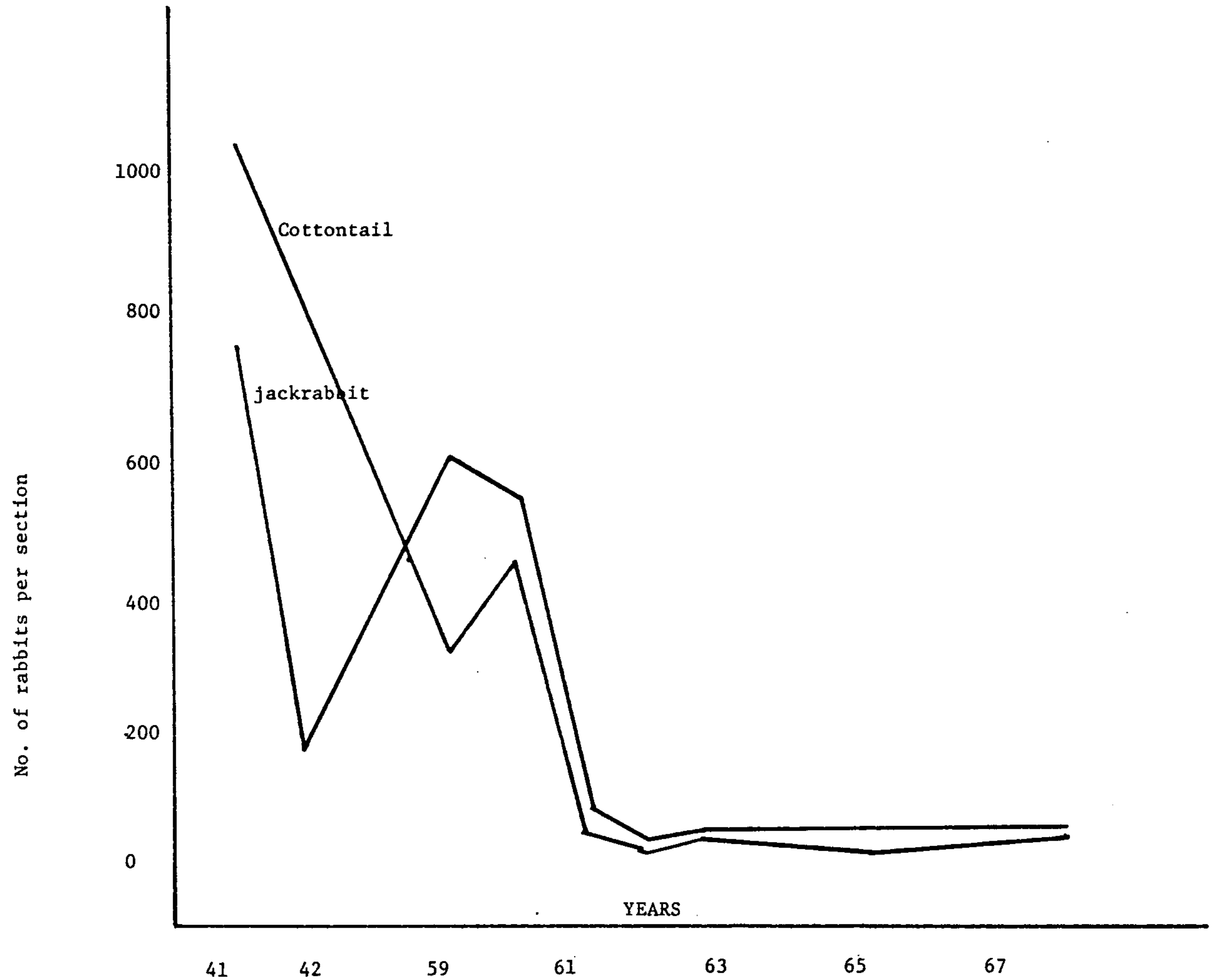


Figure 26. Rabbit population on the Jorada Range and College Ranch.

Vorhies and Taylor, (1933) using stomach analysis, found that jackrabbits in Arizona consumed 24% grass, 56% mesquite, and 3.3% cactus. Their estimation was, that 30 jackrabbits were equivalent to one sheep. However, Vorhies and Taylor made no estimation of the forage wasted or destroyed.

From these studies and other published materials it is evident that rabbits and rodents have an important impact on vegetation. Competition for available food is the most important livestock-wildlife relationship on the Jornada.

Grazing Management

Using weather and plant information, and considering livestock needs, we have developed a grazing system that will maximize livestock production while maintaining or improving the range resource. The system may be termed, "Best Pasture" (Herbel and Nelson 1969). The grazing system consists of having an objective for each pasture and stocking accordingly. The system is opportunistic in that we attempt to maximize the use of forbs and short-lived grasses because they are of little value to the permanent range resource. The plant preferences by livestock, determined for various times of the year, assisted in developing the grazing plan (Herbel and Nelson 1966). When a species is less palatable than others at a certain time of the year, the preferred species can be grazed, while in effect deferring the species that is less preferred at that time.

A salient feature of the Best Pasture Grazing System is flexibility. For example, if it rains in a part of a pasture that is being rested, and green forage develops in the form of forbs or yucca blooms, cattle can be moved to that area to take advantage of this ephemeral growth. Yucca blooms, forbs, and annual grasses, should be fully utilized when they occur because there is little advantage in saving them. Making use of this kind of vegetation is the primary reason for our cattle having sufficient vitamin A even during the driest years. In addition, supplemental feeding of energy and protein is required only in the driest springs. Figure 27 shows the protein content of rumen samples collected from cattle grazing on a mixture of grass, forbs, and browse. Had the cattle been grazing only grass, the protein content of their diet would have been below minimum NRC requirements for 9 of the 12 months (Nelson et al. 1969).

Pastures having other vegetation types can easily be incorporated into the Best Pasture System. All that is involved is determining the major forage species and when it should be grazed and rested, and stock accordingly. If it rains only on one part of the ranch, cattle can be moved to that area to take advantage of any ephemeral growth. We believe these principles can be used over wide areas, even where there is only one vegetation type. It involves a rotation scheme where the livestock are moved at no pre-determined calendar date. Rather they are moved when the vegetation on a rested pasture can be grazed to advantage to both plant and animal as compared to the pasture the livestock are currently grazing.

Flexible Herd Management

The term grazing capacity usually implies a constant level of stocking that a range will support year after year without damage to the forage resource. This concept cannot be applied to semidesert ranges, because their forage production varies greatly from year to year. The only place for the grazing capacity concept is to indicate average stocking, for example, 8 animal units per section recognizing that actual stocking has varied from 4 to 12 animal units per section. A fluctuating forage crop is a fact-of-life in this area. To assume that a range unit can be stocked at a constant level based on average years is inviting catastrophic destruction of the range resource. If a range unit must be stocked at a constant level it must be at a low enough level that forage species are not extensively overgrazed during the inevitable drought periods. This, of course, would result in a waste of forage during the average and above average years. Thus, to make maximum use of the forage resource without inflicting erreparable damage, it becomes necessary to have some form of flexible stocking.

Table 14 shows the mean and range of the perennial grass production for the 1941-66 period for two range sites on the Jornada Experimental Range. The 1941-50 period was prior to the severe drought of 1951-56. During the drought there was a shift in species composition on the deep sand site from black grama to mesa dropseed. These data illustrate the tremendous fluctuation in production occurring in our area.

Table 14. Perennial grass yield (lbs/acre).

		Shallow Sand	Deep Sand
1941-50	Mean	709	471
	Range	419 - 906	262 - 660
1951-66	Mean	273	113
	Range	110 - 452	11 - 269

Our recommendations for a flexible stocking plan are to have the herd composed of no more than 55 to 60% breeding animals during the average years. The remainder of the herd is composed of yearlings and replacement heifers. Flexible herd management, as applied to this area, begins with an appraisal of forage production each fall after the growing season. In years of low forage production, adjustments in the size and composition of the herd are planned for the winter-spring season to bring the herd within the capacity indicated by the forage appraisal. Adjustments are made in this manner: first, weaner calves are sold; second, holdover yearlings are marketed; and third, a heavier than normal culling is made in the cow herd and, when necessary, even some of the replacement heifers are sold.

In the years of above-average forage production, additional stock are added to the herd that are carried through the winter-spring period. All the natural increase from the breeding herd can be held over until spring and additional weaner calves can be purchased for winter pasturing. Depending upon the market and forage conditions, these yearlings are sold in the spring or the next fall when forage production is again appraised and the herd adjusted to meet the new situation.

The economics of flexible herd management may be studied by comparing two periods on the Jornada Range. During the period of 1927-34 an average of 1,110 animal units grazed on the Range, and 377 pounds of beef per animal unit were sold. Under the flexible system of management, an average of 780 animal units grazed the Range from 1940-51 and produced an average of 495 lbs of beef. When the same prices are used for comparing the two periods, there was a slightly higher income during the 1940-51 period despite the fact that there were 330 fewer animal units per year grazing the Range because of drier conditions and brush invasion. The major difference in the sale animals was in the numbers of weaner calves and yearlings sold. During the first period, before flexible herd management, weaner calves made up 36.5% of the beef sold and yearlings made up 30.8% of the beef sold. During the 1940-51 period, weaner calves made up only 10.0% of the beef sold while yearlings made up 56.4% of the beef sold. Flexible herd management has resulted in these added advantages: (1) more uniform annual sales, (2) a higher percentage calf crop, and (3) lower losses.

The day in implementing a program of flexible herd management is keeping records - records of stocking by pastures, records of precipitation, records of forage conditions in the fall, and records of degree of grazing use actually obtained on the pasture before the next growing season begins. Collection of such data for several years builds up records that may be used for appraisal purposes and to develop future plans. Longtime records let the manager know how the forage plants respond to fluctuating weather conditions and how grazing management can be adjusted to fit the environment that prevails in the arid Southwest. No constant stocking rate can compare with flexible stocking because the latter takes into account forage availability.

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