MARTIN, Samuel Clark, 1916-
SOME FACTORS AFFECTING VEGETATION CHANGES ON A SEMIDESERT GRASS-SHRUB CATTLE RANGE IN ARIZONA.

University of Arizona, Ph.D., 1964
Agriculture, forestry and wildlife

University Microfilms, Inc., Ann Arbor, Michigan

SOME FACTORS AFFECTING VEGETATION CHANGES ON A SEMIDESERT GRASS-SHRUB CATTLE RANGE IN ARIZONA

by

S. amuel Clark Martin

A Dissertation Submitted to the Faculty of the

DEPARTMENT OF WATERSHED MANAGEMENT

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

1964

THE UNIVERSITY OF ARIZONA

GRADUATE COLLEGE

I hereby recommend that this dissertation prepared under my direction by S. Clark Martin entitled Some Factors Affecting Vegetation Changes on a Semidesert Grass-Shrub Cattle Range in Arizona be accepted as fulfilling the dissertation requirement of the degree of Doctor of Philosophy

B. F. Wagle — Dissertation Director

May 15, 1964 — Date

After inspection of the dissertation, the following members of the Final Examination Committee concur in its approval and recommend its acceptance:*

Henry Tucker	5/15/64
Erwin M. Schmutz	5/15/64
Edwin B. Kurtz	5/15/64
W. S. Phillips	5/15/64
B. F. Wagle	5/15/64
A. L. McComb	5/15/64

*This approval and acceptance is contingent on the candidate's adequate performance and defense of this dissertation at the final oral examination. The inclusion of this sheet bound into the library copy of the dissertation is evidence of satisfactory performance at the final examination.

STATEMENT BY AUTHOR

This dissertation has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this dissertation are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: A. Clark Martin

ACKNOWLEDGMENTS

Completion of this dissertation has been facilitated by the efforts, encouragement, and support of many people. The largest group to whom credit is due are those workers, past and contemporary, who have recorded results and observations related to the management of semidesert range.

Special appreciation is expressed to Dr. Robert F. Wagle and Dr. Ervin M. Schmutz, who became chairman and member, respectively, of my graduate committee late in the program, when the work load was greatest. Throughout the study period Dr. Robert R. Humphrey's encouragement as major professor and Dr. Henry Tucker's guidance on statistical matters have been most valuable.

Raymond Price, Director of the Rocky Mountain Forest and Range Experiment Station, made the records and facilities of the Santa Rita Experimental Range available for the study and provided technical guidance through Elbert H. Reid, Jacob Kovner, and other members of his immediate staff. Dwight R. Cable did most of the field work and much of the preliminary computation.

Finally, too much credit cannot be given to the sustained encouragement I have received from my wife, daughter, and son despite the many occasions when family plans were altered to meet academic requirements.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

TABLE OF CONTENTS--Continued

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF TABLES--Continued

LIST OF ILLUSTRATIONS

ABSTRACT

Martin, S. Clark. SOME FACTORS AFFECTING VEGETATION CHANGES ON A SEMIDESERT GRASS-SHRUB CATTLE RANGE IN ARIZONA. Ph.D. Dissertation, Department of Watershed Management, The University of Arizona, 1964.

A 5-year grazing study testing the effects of winter, summer, and yearlong grazing on semidesert cattle range was conducted in southern Arizona from 1957 to 1961. Superimposed on the grazing treatments were measurements of the effects of distance from water, texture of subsoil, and mesquite control.

Responses to treatments were measured in terms of the production and utilization of grasses and the ground cover of perennial grasses and shrubs. Individual species and groups of grasses considered were Arizona cottontop (*Trichachne californica* [Benth.] Chase), tall three-awns (*Aristida ternipes* Cav. and *A. hamulosa* Henr.), Santa Rita three-awn (*A. glabrata* [Vasey] Hitchc.), bush muhly (*Muhlenbergia porteri* Scribn.), annual grasses, all perennial grasses, and total grasses. Shrub species considered were velvet mesquite (*Prosopis juliflora* [Swartz] D.C. var. *velutina* [Woot.] Sarg.), burroweed (*Aplopappus tenuisectus* [Greene] Blake) and all shrubs combined.

Interpretation of results was complicated by initial differences among grazing units, by rainfall variation among

years and study units, and by the fact that there were only two replications of the season of grazing treatments.

Total grass production averaged 200 pounds per acre of which 150 pounds was annual grass. The lowest average yield was 54 pounds in 1957 and the highest was 334 in 1959. Yields of annual grasses varied much more from year to year than did yields of perennial grasses. Year-to-year differences were as great or greater than differences among treatments.

Perennial grass production was highest on yearlong range but this difference is believed to be due to higher rainfall on the yearlong units rather than to yearlong grazing. The winter-grazed units produced more perennial grasses than did the summer units. The superiority of winter grazing over summer grazing is believed to constitute a real treatment effect and was greatest at 1 mile from water. Yields of annual grasses were not significantly affected by season of grazing.

Perennial grass yields increased with distance from water but yields of annual grasses did not, indicating that the annual grasses were less sensitive than perennial grasses to differences in grazing pressure.

Soils with accumulations of clay in the subsoil supported more perennial grass but less annual grass than soils having sandy or gravelly subsoils. Exploration of certain interactions showed that plots with clayey subsoils produced more grass on parts of the study area having higher elevation and rainfall but that plots with gravelly subsoils yielded more grass on the lower and drier parts of the range.

Mesquite ground cover (crown intercept) averaged 5.33 percent and was about equally abundant on fine- and coarse-textured subsoils. Mesquite cover was greater on summer range than on winter or yearlong range and much greater on one of the two blocks of pastures than on the other. These differences were present at the start of the study and were not due to treatment effects.

Burroweed ground cover averaged 2.83 percent over all treatments and years. Burroweed was most abundant on summer range at the 1/4-mile distance from water, on the mesquite-free plots, and in the years following a wet spring or a wet winter.

Of all treatment effects measured, mesquite control showed the most consistent effects.

INTRODUCTION

This study was undertaken to evaluate several factors that either have been reported to affect forage production on semidesert cattle ranges or that appear to do so.

The semidesert grass-shrub ranges of southern Arizona lie approximately between 3,000 and 4,500 feet in elevation and between 10 and 20 inches average annual rainfall. They have been included in such ecological groupings as "Mesquite Grass" (Shantz and Zon 1924), "Desert Plains" (Weaver and Clements 1929), "Desert Grass" (Nichol 1937), "Mesquite-Grassland" or "Mesquite-half-shrub" (Darrow 1944), and "Desert Grassland" (Humphrey 1958). Many of the semidesert grass-shrub ranges have declined in productivity since they were settled almost a century ago. The better perennial grasses were reported to have been almost eliminated and increases in woody plants were observed on some ranges before 1900 (Griffiths 1901). Deterioration is still in progress on many semidesert ranges and economical methods for increasing forage production are needed.

Experience and research have revealed much about semidesert cattle ranges and their management. Forage yields have been observed to be strongly influenced by the amount and distribution of rainfall (Nelson 1934, Lister and Schumacher 1937). Moderate grazing has helped maintain forage stands, but excessive grazing has been destructive (Culley 1937 and 1941, Canfield 1939). The strong influence of edaphic factors on the kind and amount of vegetation that develops under a given climatic regime has been noted by Campbell (1931). The inverse relationship between density of mesquite and perennial grass production has been widely recognized (Campbell 1929, Streets and Stanley 1938, Upson and Cribbs 1937). Finally, the importance of grazing forage plants at the right time has been accepted generally (Sampson 1919, Nelson 1934, McCarty and Price 1942) although the effects of grazing at different seasons have not been extensively studied in the Southwest.

By simultaneously studying the effects of several factors, it has been possible in this investigation to more completely evaluate the influences of these factors than has been done previously.

STUDY AREA

The study was conducted on the Santa Rita Experimental Range about 30 miles south of Tucson, Arizona (Figure 1). Pastures 2N, 3, and 12B constituted block 1. Block 2 was made up of pastures 5N, 5S, and 6B. Pasture 3, with an area of 4,044 acres, was the smallest unit; and pasture 5N, with an area of 5,504 acres, was the largest. The total area involved was about 28,000 acres.

The study area is a gently sloping bajada dissected by numerous shallow, dry washes. The range in elevation is from 2,900 to 4,000 feet. Vegetation is characterized by a sparse to very sparse stand of perennial grasses overtopped by shrubs. The vegetation increases in density with increasing rainfall and elevation.

Arizona cottontop (*Trichachne californica*),[1] tall three-awns (a term applied here without distinction to *Aristida ternipes* and *A. hamulosa*), Santa Rita three-awn (*A. glabrata*), black grama (*Bouteloua eriopoda*), Rothrock grama (*B. rothrockii*), and bush muhly (*Muhlenbergia porteri*) are the more common perennial grasses.

The major shrubs include velvet mesquite (*Prosopis juliflora* var. *velutina*), catclaw acacia (*Acacia greggii*),

---

1. Scientific names of plants used in this paper are from Kearney and Peebles (1951).

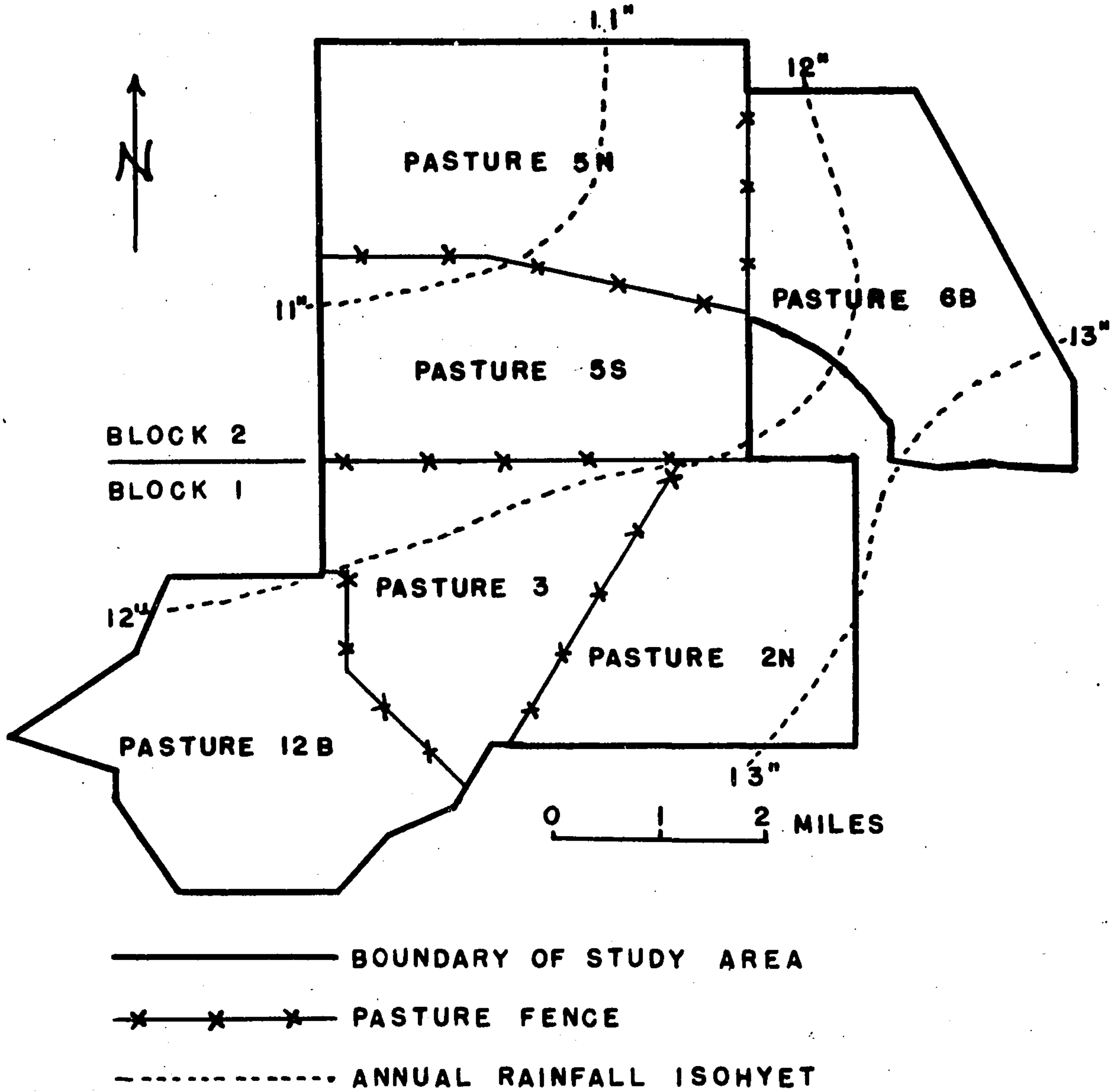

Fig. 1. Map of that part of the Santa Rita Experimental Range assigned to the study, showing arrangement of pastures and rainfall zones.

jumping cholla (Opuntia fulgida), staghorn cholla (O. spinosior), Engelmann's prickly pear (O. engelmannii), and burroweed (Aplopappus tenuisectus).

Precipitation data have been recorded continuously on the study area since 1922. Average annual rainfall ranges from 10 inches at the lowest elevation to about 14 inches at the highest. Year-to-year changes in the amount and distribution of precipitation on semidesert range are often so great that they override other causes of change in the vegetation. Herbage production in a drought year may be less than one-fifth as great as that produced in a wet (relatively high rainfall) year. And wet, dry, and average years succeed each other in apparently random sequence.

Natural periods of growth for herbaceous vegetation in southern Arizona make it reasonable to divide the year into three 4-month seasons. Spring (February 1 - May 31) includes the period during which growth is made either from moisture accumulated before the onset of favorable temperatures or from precipitation during the period. June 1 to September 30 includes the active summer growing season which usually is limited to a few weeks in July and August. Almost no rainfall falls in May or June and soil moisture usually drops below the wilting point for herbaceous plants. This 2-month dry period clearly separates the spring and summer growing seasons. For lack of a better term, the period from October 1 to January 31 is called winter.

Except for pasture 12B, all of the study area was first fenced for experimental purposes in 1903. Pasture 12B was added to the experimental range in 1926 and almost certainly was grazed heavily up to that time. Since 1926, grazing in 12B has been comparable to that in the other five study units. This difference in history may account in part for the fact that pasture 12B has more mesquite than any other unit in the study.

The five range units which were in the original fenced tract were not grazed from 1903 until 1915. Grazing since 1915 has been at rates considered conservative by the standards of the time. However, during this period the standards have been revised downward several times.

At the outset it was obvious that the six range units in the study were not alike. Pasture 5N lay at the lowest elevation and received the least rainfall. Pastures 2N and 6B were most favorably located at the highest elevation and rainfall. The distribution of livestock water and the relative densities of grasses and shrubs also differed from unit to unit. These initial differences complicated the interpretation of treatment effects.

METHODS OF STUDY

The general plan of the study involved grazing treatments applied to entire pastures and sampling within the pastures to obtain data on other influences. Pasture-wide treatments in the study were summer, winter, and yearlong grazing. Each grazing treatment was applied to one pasture in each of two blocks. The three grazing treatments provided opportunities to study relationships between season of grazing and other influences by taking samples only at 1/4, 5/8, and 1 mile from water on sites with fine- and coarse-textured subsoils and by killing the mesquite on one of the two plots at each location. The effects of season of grazing, distance from water, subsoil texture, and mesquite control were measured in terms of the herbage production, utilization, and ground cover of perennial grasses, the herbage production of annual grasses, and the ground cover of shrubs. The study included annual measurements taken on permanent plots over a 5-year period.

Known sources of variation included both imposed treatments and non-treatment variation. The imposed treatments were three seasons of grazing, mesquite control, three distances from water, and two subsoil textures. The obvious non-treatment sources of variation were the inherent differences among grazing units in vegetation, elevation, and rainfall, and year-to-year differences in the amount and distribution of rainfall.

Treatments

Assignment of the season-of-grazing treatments to study units was not random, but was controlled by the availability of permanent livestock water. Pastures 2N and 6B were chosen for yearlong grazing because they had two and three permanent watering places respectively, and because these were the units most likely to always have a supply of forage. Pastures 5N and 3 were picked for winter grazing because they were relatively the most dependent on ponds for stock water. The ponds are most likely to contain water during the fall and winter. With the yearlong and winter units selected, pastures 5S and 12B remained for summer grazing.

Twelve sampling sites were selected in each pasture. Tentative selection was first made with the aid of a soils map so that half of the sites would fall on areas with fine-textured subsoils and half on coarse-textured subsoils. Within each soil type two sites were selected at 1/4 mile, two at 5/8 mile, and two at 1 mile from water. Two plots were established at each sampling site. Each plot was 100 feet wide (east-west) and 200 feet long (north-south) and was centered over a 100-foot permanent line transect. The two plots lay parallel to each other and were separated by a 50-foot isolation strip. The line transects were marked at the 0-, 50-, and 100-foot positions with metal stakes and the site was marked for easy location by a metal fence post midway between the "0" ends of the transects.

The number of mesquite on each 100- by 200-foot plot was counted in the fall of 1957 at the start of the study. The mesquites on the plot with the smaller number of trees were then killed with diesel oil. The plot with the smaller number of trees was selected for mesquite control in order to establish as great a difference as possible between mesquite-killed and mesquite-alive plots. Since diesel oil did not kill all the mesquite plants quickly, some follow-up treatment in 1958 was necessary and the effects of complete control were first reflected in the 1959 measurements.

Kinds of Data Taken

The effects of the treatment and non-treatment influences were measured in terms of herbage production, utilization of perennial grasses, and ground cover. Herbage yield data were taken separately for annual grasses and for each species of perennial grass. Yields were estimated ocularly in the fall, usually in October, each year on two permanently located 8- by 24-foot subplots on each plot. Herbage on temporary plots was estimated, then clipped and weighed to establish a regression relationship for adjusting ocular estimates on the permanent plots using the method described by Wilm, Costello and Klipple (1944). Herbage clipped from temporary plots was reweighed when air dry to provide factors for converting field estimates to air-dry weights. Yield data were recorded separately for Arizona cottontop, tall three-awns, all perennial grasses, annual grasses, and total grasses.

Utilization data were taken by species on perennial grasses only using the ungrazed-plant-count method (Roach 1950). Observations at each plot were confined to an area approximately 100 by 200 feet centered over the permanent line transect. Major species or groups for which utilization data were analyzed were Santa Rita three-awn, tall three-awns, bush muhly, and Arizona cottontop, and all perennial grasses combined.

Ground cover estimates were obtained by the line interception method (Canfield 1941) using one 100-foot transect per plot. The data collected included basal intercept by species for the perennial grasses and crown intercept by species for shrubs. Statistical analyses were applied only to the basal intercept data for all perennial grasses and to the crown intercept data for mesquite, burroweed, and all shrubs combined.

Experimental Design

The design of the study was a split-split-split plot with seasons of grazing as whole plot treatments. The study included data for the 5-year period 1957 to 1961. These yearly observations constituted subplot effects as has been illustrated by Wilm (1945).

The data on distance from water and texture of subsoil offered the choice of considering one of the factors to be nested within the other thereby providing second and third splits in the analysis or that of considering the two factors parallel and testing both with the same error term. Since there seemed to be no good reason for nesting soils within distances or distances within soils, the latter course was taken.

The third split in the analysis resulted from killing the mesquite on one member of each pair of plots at each site.

The weakness of the design for testing effects of season of grazing was recognized at the outset. The decision to go ahead with the study despite this limitation was based on several considerations. First, enough suitable pastures for an additional replicate were not available and funds were not available to establish more units on the same area by additional cross fencing and water development. Second, large differences were thought necessary to be of practical value and it was decided that the treatments would not be considered worthwhile if measurable differences were not obtained within a period of 5 years. Third, if the pastures had been subdivided to provide more replications for season-of-grazing treatments, this would have reduced the size of the experimental units so much below the average size of units on ranches that the hazards of extrapolation would have been increased. Fourth, the split-split-split plot design provided relatively sensitive tests for the direct effects of distance from water, texture of subsoil, and mesquite control and for their interactions with each other and with season of grazing. Finally, the design provided opportunities to study sources of variability within the study area by examining the block-by-treatment interactions.

Statistical Analysis

The analysis of variance outlined in Table 1 was applied to each of 14 sets of data. Since a major objective in the study was to explore sources of variability within the study area, the season of grazing and block influences were both considered fixed. The year effects were considered random and were included along with block and season of grazing in the whole plot portion of the analysis of variance. Having made these assumptions, the appropriate error terms in the whole plot analysis were selected on the basis of the expectations of mean squares (Schultz 1955). Thus, in the whole plot analysis, the block and year effects were tested against the block-by-year interaction; season of grazing against the grazing-by-year interaction; and, all two-way interactions against the three-way.

Table 1. Outline of analysis of variance applied to data collected on selected variables.

Source of Variation	Degrees of Freedom
Blocks	1
Grazing seasons	2
Years	4
Grazing x year	8
Block x grazing	2
Block x year	4
Block x grazing x year	8
Soils	1
Distances	2
Soil x distance	2
Soil x grazing	2
Soil x year	4
Distance x grazing	4
Distance x year	8
Soil x distance x grazing	4
Soil x distance x year	8
Soil x grazing x year	8
Grazing x distance x year	16
Soil x distance x grazing x year	16
Error b	75
Replications within SxDxGxBxY	180
Mesquite control	1
Mesquite x soil	1
Mesquite x distance	2
Mesquite x grazing	2
Mesquite x year	4
Mesquite x soil x distance	2
Mesquite x soil x grazing	2
Mesquite x soil x year	4
Mesquite x distance x grazing	4
Mesquite x distance x year	8
Mesquite x grazing x year	8
Mesquite x soil x distance x grazing	4
Mesquite x soil x distance x year	8
Mesquite x soil x grazing x year	8
Mesquite x grazing x distance x year	16
Mesquite x soil x distance x G x Y	16
Mesquite x block	1
Error c	89
Replications within MxSxDxGxY	180
Total	719

Subplot error terms ("b" and "c") were composed of the block (replication) interactions with all other effects at their respective levels of subdivision in the analysis (Cochran and Cox 1957).

The soil-by-block and distance-by-block mean squares were computed separately and tested against their respective interactions with years.

Means for main effects and first order interactions having significant F values were evaluated by multiple range tests (Duncan 1955). Most statements of results are supported by tests that exceed the 5 percent tabular values.

The analysis of variance and the multiple range tests were designed to reveal differences between blocks of pastures and between years as well as differences associated with season of grazing, distance from water, subsoil texture, and mesquite control. All data (720 observations) of a given class were used in every comparison.

ENVIRONMENTAL EFFECTS

The major environmental effects considered were differences among years which were partly due to rainfall variation and partly to other factors, and natural differences among pastures assigned to the season of grazing treatments. The block-by-year interactions are also considered in this section.

Rainfall During the Study Period

The period from 1956 to 1961 included some unusual precipitation events (Table 2). By most standards, 1956, the year before the study began, was the driest on record. The spring of 1961 also was very dry.

On the favorable side, the spring and summer of 1958 and the winter of 1959-1960 were among the wettest recorded. Wet springs followed immediately by wet summers, as happened in 1958, are unusually rare.

Since summer rainfall is especially important in forage production, the rainfall record for the period from June 1 - September 30 is presented in more detail (Table 3). The winter-grazed pasture of block 1 received about three-fourths inch more summer rainfall during the 5-year period 1957-1961 than the winter unit of block 2 despite a 1-inch reversal in

Table 2. Average precipitation on the study area by 4-month seasons, 1955-1961

Season	Year					
	1955-1956	1956-1957	1957-1958	1958-1959	1959-1960	1960-1961
	Inches					
Oct. 1 - Jan. 31	2.73	2.40	2.69	1.74	5.38	2.83
Feb. 1 - May 31	0.70	1.30	4.46	0.54	1.12	0.31
June 1 - Sept. 30	3.18	6.46	9.00	7.64	6.00	7.46
Total	6.61	10.16	16.15	9.92	12.50	10.60

Table 3. Summer precipitation by pasture and block, 1956-1961

Pasture[a]	Block	1956	1957	1958	1959	1960	1961	Average[b]
		Year						
		Inches						
Winter	1	3.49	6.22	8.58	8.69	5.95	7.62	7.41
	2	2.91	5.12	9.62	6.04	5.65	6.82	6.65
	Average	3.20	5.67	9.10	7.36	5.80	7.22	7.03
Summer	1	3.76	7.17	7.45	8.73	5.46	6.90	7.14
	2	2.84	5.55	9.46	7.33	5.85	7.38	7.11
	Average	3.30	6.36	8.46	8.04	5.66	7.14	7.13
Yearlong	1	3.30	6.59	9.26	8.31	6.70	8.18	7.81
	2	2.79	8.10	9.62	6.71	6.37	7.84	7.73
	Average	3.04	7.34	9.44	7.51	6.54	8.01	7.77
All	1	3.52	6.66	8.43	8.58	6.04	7.57	7.45
	2	2.85	6.26	9.57	6.69	5.96	7.35	7.16
	Average	3.18	6.46	9.00	7.64	6.00	7.46	7.31

[a]Pastures are designated by season of grazing

[b]Average does not include 1956

the summer of 1958. Summer rainfall means for the summer and yearlong ranges were less than 0.1 inch higher in block 1 than in block 2. Thus, most of the differences between blocks in summer rainfall means was between the winter-grazed pastures.

Summer rainfall differences between summer and winter pastures averaged only 0.1 inch but rainfall on the yearlong units was greater than on the winter and summer units by 0.64 and 0.74 inch respectively. Comparisons between winter and summer units revealed that the winter unit received 0.27 inch more rainfall in block 1 but 0.46 inch less in block 2.

Thus these data indicate that vegetation differences attributable to differences in summer rainfall should be greatest between blocks for the winter-grazed units and greatest among seasons between yearlong units and those grazed either in winter or summer.

Differences Among Years

Differences among years resulted from differences in growing conditions, mainly rainfall, and from progressive changes resulting from the treatments. The benefits of mesquite control and the effects of different seasons of grazing were assumed to be cumulative. Generally speaking, the cumulative effects of treatments were smaller than the year-to-year changes resulting from differences in the amount and distribution of precipitation.

Herbage Production

The production of total grass herbage was lowest in 1957, a relatively dry summer following the severe summer drought of 1956 (Table 4). By comparison, production in 1960, the driest summer of the study period which followed two consecutive favorable rainfall summers, did not drop so low as in 1957. The most spectacular rise in perennial grass production was from 1957 to 1958 when the combination of high spring and high summer rainfall provided an unusually favorable set of conditions for grass growth. In fact, total yields of perennial grasses were greatest in 1958. However, annual grass yields were highest in 1959. Since the winter and spring preceding the summer of 1959 were both dry, it is apparent that high cool-season rainfall is not needed to produce abundant crops of warm-season annual grasses.

The magnitude of year-to-year fluctuations in yield were much greater for annual grasses than for perennials (Figure 2). The lowest yields of annual and perennial grasses were 11 and 31 percent of their respective highs. These data show that the annual grasses are a relatively unreliable source of forage even though they produce abundantly in high rainfall years. The data also show that spectacular gains in perennial grass production can be made in a single year if a favorable spring growing season is followed in the same year by a favorable summer growing season.

Table 4. Differences between years in herbage production, utilization of perennial grasses, and ground cover[a]

Plant class or species	1957	1958	1959	1960	1961	Sign. level (percent)
			HERBAGE PER ACRE (POUNDS)			
Arizona cottontop	9.88	29.31	23.70	17.53	20.17	5
Tall three-awns	2.36	11.79	10.30	9.67	5.73	5
All perennial grasses	23.91	77.76	61.56	46.33	47.33	1
Annual grasses	29.88	203.08	272.26	50.57	185.80	1
Total grass	53.78	280.84	333.82	96.90	233.18	1
			UTILIZATION (PERCENT)			
Arizona cottontop	48	41	45	58	58	NS
Tall three-awns	08	24	32	41	30	5
Santa Rita three-awn	55	46	54	66	53	NS
Bush muhly	46	48	43	60	51	5
All perennial grasses	37	34	40	53	45	NS
			GROUND COVER (PERCENT)			
All perennial grasses	0.12	0.25	0.15	0.08	0.09	1
Burroweed	2.35	3.84	1.58	4.16	2.20	1
Mesquite	7.03	6.33	4.72	4.21	4.34	1
All shrubs	13.30	14.77	10.22	12.30	9.95	1

[a]Basal intercept of perennial grasses; crown intercept of shrubs

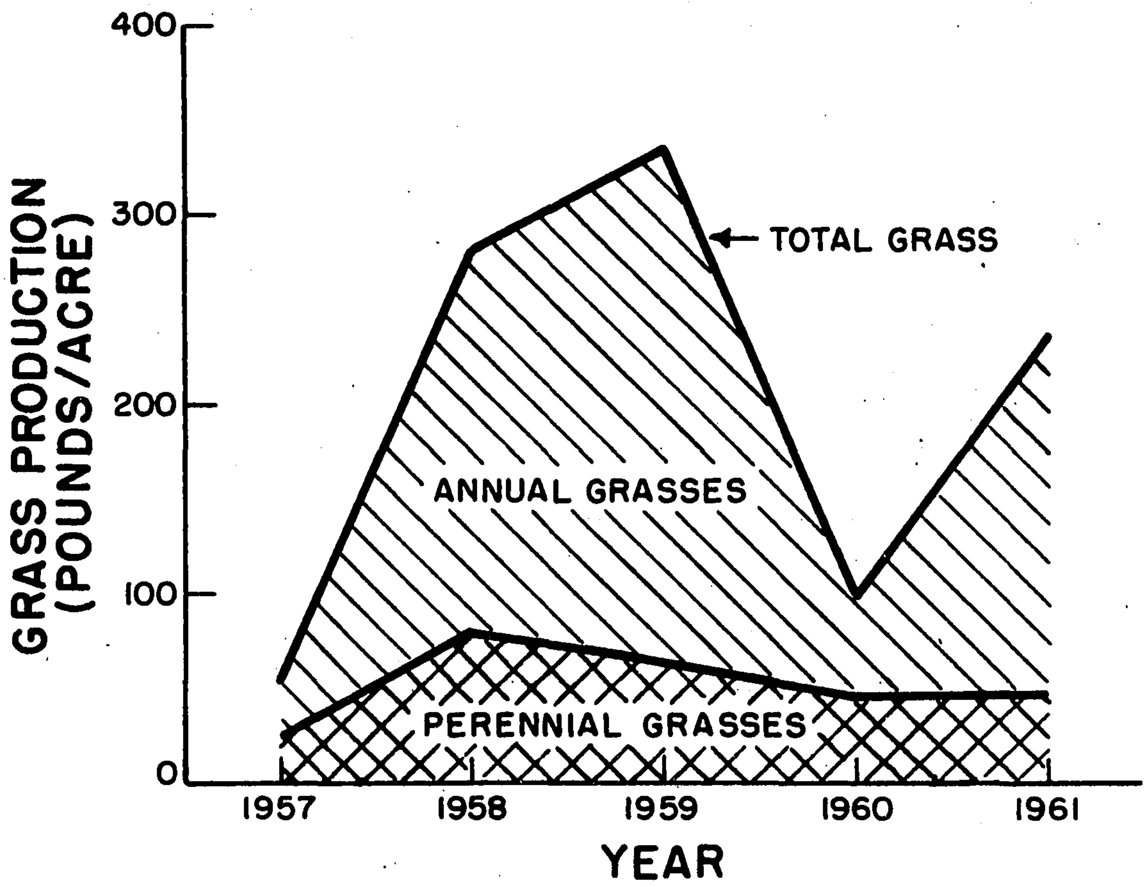

Fig. 2. Total yearly herbage production showing relative contributions of annual and perennial grasses.

Utilization of Perennial Grasses

Except for tall three-awns and bush muhly, year-to-year differences in utilization were not significant. The highest utilization on both species was recorded on the relatively light forage crop of 1960. Among species, use was consistently highest on Santa Rita three-awn, followed closely by bush muhly and Arizona cottontop. The tall three-awns always showed the lightest use.

Ground Cover

All analyses of intercept data showed significant differences among years at the 1-percent level (Table 4). Perennial grass cover was highest in 1958, and lowest in 1960 and 1961. It is apparent from these data that the basal cover, as well as herbage yield, of perennial grasses can increase or decrease rapidly, depending on the climatic situation. This indicates that range improvement is not necessarily slow in a semidesert climate, but marked improvements probably occur only in unusually favorable years.

The year-to-year variability in cover of burroweed was striking and did not coincide with that of the perennial grasses. Burroweed cover was greatest in 1958 and in 1960, and least in 1959. These changes are attributed to differences in winter and spring precipitation (Table 2). A moderately wet winter followed by a wet spring caused the increase in burroweed in 1957-1958. A dry winter followed by a dry spring in 1958-1959 caused a burroweed decrease. The wettest winter on record, 1959-1960, was followed by a moderately dry spring and burroweed cover reached its greatest peak. The above-average cool season moisture favored the establishment of burroweed seedlings and the expansion and thickening of the crowns of older plants.

Some of the year-to-year differences in mesquite cover were the result of mesquite control treatments. The 1957 measurement was made before mesquite was killed on the mesquite-free plots, and the measurement in 1958 was made before all the mesquites on these treated plots had died. Since 1959, the mesquite intercept on mesquite-free plots has been negligible, and the average intercept for all plots in the study has been relatively constant.

Differences Between Blocks

Differences between blocks were evident in almost all sets of data (Table 5). Production, utilization, and ground cover of perennial grasses, and crown cover of shrubs were all greater in block 1 than in block 2.

Herbage Production

Arizona cottontop and tall three-awns produced more than two and one-half times as much in block 1 as in block 2

Table 5. Differences between blocks in herbage production, utilization of perennial grasses, and ground cover[a]

Plant class or species	Block 1	Block 2	Sign. level (percent)
	HERBAGE PER ACRE (POUNDS)		
Arizona cottontop	29.82	11.31	1
Tall three-awns	11.79	4.15	5
All perennial grasses	59.86	42.89	5
Annual grasses	106.51	190.13	NS
Total grass	166.40	233.02	NS
	UTILIZATION (PERCENT)		
Arizona cottontop	56	44	5
Tall three-awns	32	22	1
Santa Rita three-awn	58	51	5
Bush muhly	53	46	5
All perennial grasses	48	35	1
	GROUND COVER (PERCENT)		
All perennial grasses	0.16	0.11	1
Burroweed	4.12	1.54	5
Mesquite	8.17	2.48	1
All shrubs	15.78	8.56	1

[a]Basal intercept of perennial grasses; crown intercept of shrubs

(Table 5). Perennial grasses as a group produced 40 percent more in block 1 than in block 2.

Block differences for annual grasses and total grass, though not significant, were the opposite of those for perennial grasses. Average yields for annual grasses were 78 percent higher in block 2 than in block 1. This, combined with the higher yield of annual grasses, made the total grass production 40 percent higher in block 2. Annual grasses made up 82 percent of the total grass herbage in block 2 but only 64 percent in block 1.

Utilization of Perennial Grasses

Grazing use was higher in block 1 than in block 2 for all classes of perennial grasses for which data were analyzed. The tall three-awns showed the lightest use in both blocks and the greatest relative difference between blocks. Utilization on tall three-awns was 32 percent in block 1 and 22 percent in block 2. Use of Arizona cottontop was 56 percent in block 1 and 44 percent in block 2. For all perennial grasses, including several minor species not listed in the table, utilization was 48 percent in block 1 and 35 percent in block 2.

Ground Cover

All ground cover means tested were significantly higher in block 1 than in block 2. The basal intercept of perennial grasses was 1.4 times greater, the crown intercept of burroweed 2.7 times greater, and that of mesquite 3.3 times greater in block 1 than in block 2. The total shrub cover was almost twice as great in block 1 as in block 2.

The block differences show that block 1, despite higher average utilization and greater brush cover, supported a greater cover of perennial grasses and produced more perennial grass herbage than did block 2. These data suggest that other differences between the two blocks were great enough to override the effects of differences in utilization and shrub cover.

Some of the differences in vegetation between blocks may be explained by the fact that the longtime average rainfall in block 1 is somewhat higher than in block 2. Approximate 1-inch rainfall isohyets superimposed on a map of the study area (Figure 1) show that only 10 percent of the total area of block 1 falls below the 12-inch isohyet of annual rainfall, but that 76 percent of block 2 receives 12 inches of rainfall or less (Table 6). Differences in annual rainfall are greatest between the winter-grazed units and least between units grazed yearlong. Differences between blocks in yield and cover of perennial grasses were also greatest between the winter-grazed units.

Shreve (1931) observed that conditions in the shade of desert trees and shrubs were more favorable than in unshaded areas for herbaceous annuals and seedling perennials. Thus,

Table 6. Relative portions of each block and pasture that received specified amounts of average annual precipitation

Block	Pasture[a]	Inches of annual precipitation			
		10-11	11-12	12-13	13-14
		Percent			
1	Yearlong	0	0	93	7
1	Winter	0	26	74	0
1	Summer	0	4	96	0
	Average	0	10	88	2
2	Yearlong	0	26	57	17
2	Winter	58	42	0	0
2	Summer	8	92	0	0
	Average	24	52	18	6

[a]Pastures are designated by season of grazing

it is possible that, because of higher average rainfall, block 1 supports more shrub cover and consequently more perennial grass.

Before concluding that heavy brush cover promotes grass production, however, it is well to remember that yield of annual grasses and total grass yields were greater on block 2 where the shrub cover was lighter. This result was not surprising because while the trees and shrubs make a small part of the land surface more favorable for plant growth by shading, they make the much larger unshaded area less favorable by withdrawing soil moisture that might otherwise be available for growing grass. Shrub cover differences between blocks were related inversely to the yields of annual grass herbage.

Block-by-Year Interactions

In several sets of data the differences between block means were not of the same magnitude in all years. These interactions are discussed briefly because they were major sources of variation in this study and should be considered in planning any extensive grazing study on semidesert range.

Herbage Production

Annual grass production and total grass production were much higher in block 2 than in block 1 in 1958 and 1961 (Appendix A). Higher summer rainfall in 1958 on block 2 could explain the difference in that year, but there was essentially no difference between blocks in recorded summer rainfall in 1961 (Table 3).

Utilization of Perennial Grasses

There were no block-by-year interactions in the utilization data for perennial grasses (Appendix B).

Ground Cover

The only block-by-year interactions in ground cover measurements were those for burroweed and all shrubs (Appendix C). The all-shrub intercept was exceptionally high in block 1 in 1957, 1958, and 1960. In block 2, 1957 and 1958 were relatively high, but the all-shrub intercept in 1957 was not significantly greater than in 1959, 1960, or 1961. These changes in all-shrub intercept are explained largely by changes in cover of mesquite and burroweed.

The relatively high values for all shrub cover in 1957 and 1958 were due partly to the presence of live mesquite crowns on plots where the mesquite was being killed (Figure 3). The apparent effect was greater in block 1 because the mesquite crown cover was greater and removing the mesquite made a greater difference than in block 2.

The crown intercept measurements for burroweed were much higher in block 1 than in block 2, as were the peaks in burroweed cover in 1958 and 1960. The large burroweed intercept in 1958 was coupled with a relatively large mesquite

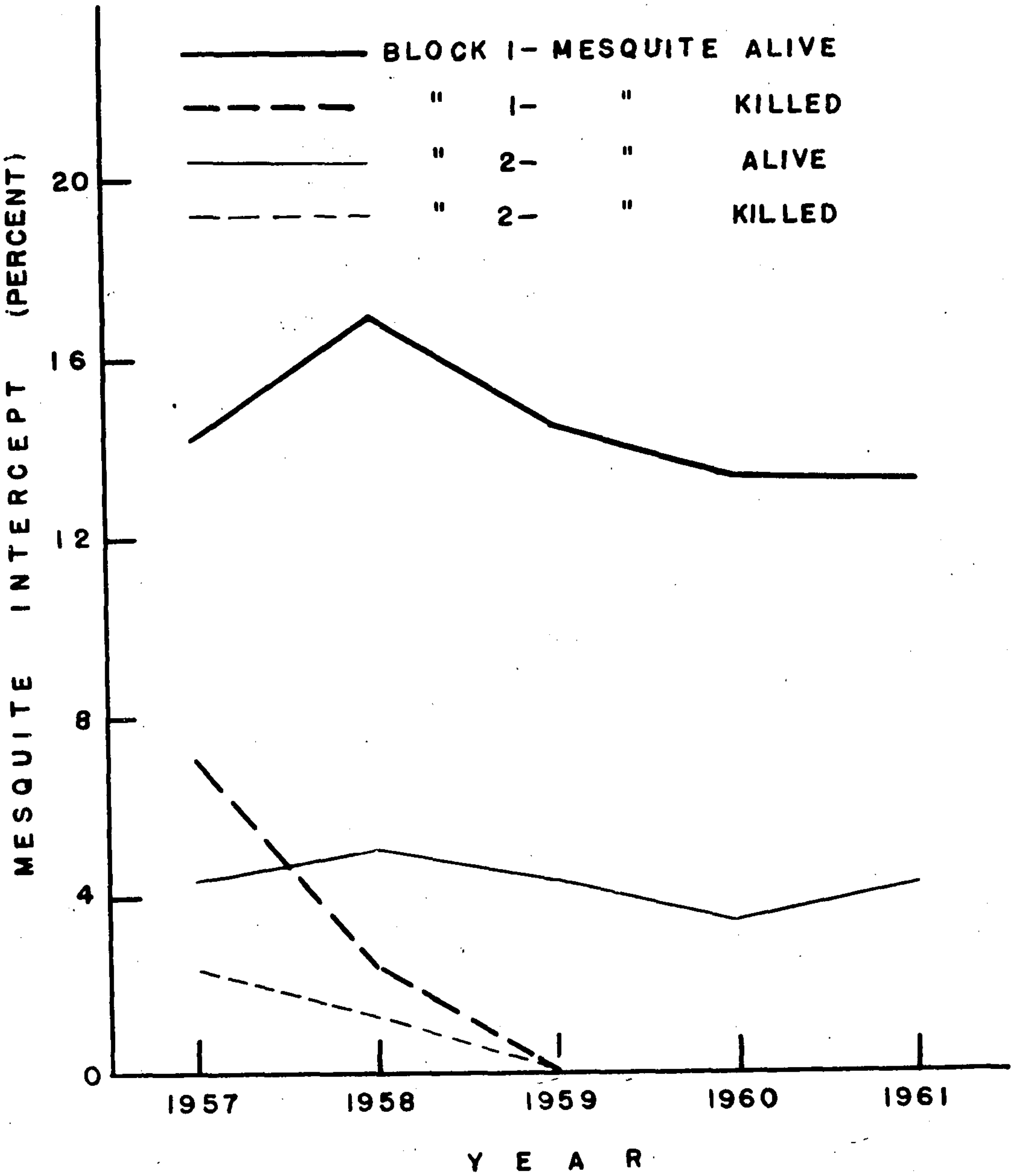

Fig. 3. Yearly crown intercept of mesquite on mesquite-alive and mesquite-killed plots of block 1 and block 2.

30
3

intercept. A marked increase in burroweed was largely responsible for the 1960 peak in all-shrub intercept in block 1.

EFFECTS OF DISTANCE FROM WATER

Locations of sites for making observations on the vegetation were restricted to specific distances from water. This was done with the expectation that intensity of utilization on the perennial grasses would be related inversely to distance. Thus, while the overall objective was to utilize 40 percent of the perennial grass herbage produced in one summer by June 30 of the succeeding year, it was anticipated that average use at 1/4 mile from water would exceed 40 percent and that use at 1 mile from water would be less than 40 percent. The purposes of this distance sampling were to determine whether distance from water was significantly related to utilization of perennial grasses and whether the observed differences in utilization were associated with differences in ground cover and yield of perennial grasses or other vegetation measurements.

Background Information

A generalized standard for proper use is provided by Ellison (1956), who stated: "Use is proper only if we have definite evidence before our eyes which indicates (1) that plant cover is maintaining itself or increasing, and (2) that desirable species are maintaining themselves or increasing at the expense of less desirable ones. . . ."

Schuster (1964), Weaver and Albertson (1940), Weaver (1950), and Bowns and Box (1964) all reported decreases in the depth, number, and weight of roots with excessive grazing. Cook et al. (1953) reported that with heavier utilization animals were forced to consume the less nutritious portions of the plants. Klipple and Bement (1961) found that light grazing increased the herbage-yielding ability of native range.

Intensity of grazing studies reported by Johnson (1953 and 1956) showed that moderate grazing (35 to 40 percent utilization) produced the greatest beef gains on a per-acre basis, that herbage production was inversely related to intensity of use, that blue grama produced most on heavily grazed range where mountain muhly and Arizona fescue produced the least. Crested wheatgrass withstood grazing to a 2-inch stubble height while a 4-inch stubble height was necessary to maintain smooth brome (Johnson 1959). Klipple and Costello (1960) found that 60 percent use on short grass was destructive, that 40 percent use maintained the dominant grasses, and that 30 percent use permitted the highly palatable species to increase. Pond (1960) found that 50 percent use was detrimental for Idaho fescue and Beetle et al. (1961) reported that 40-45 percent use was proper for this species. On the basis of these published findings, the average utilization objective for perennial grasses was set at 40 percent.

Enough suitable grazing units were not available to apply different intensities of grazing to entire pastures. However, it was assumed that intensity of grazing use would be related inversely to distance from water. This assumption is supported by common observation and by the work of Glendening (1944) who found that use on pine bunchgrass ranges decreased about 6 percent per one-fourth mile of increased distance from water.

Results of Distance-from-Water Study

Measurements of all variables were made at 1/4, 5/8, and 1 mile from water. Differences due to distance were most consistent in the data for herbage production of perennial grasses, ground cover of perennial grasses and burroweed; and were least consistent with respect to grazing use (Table 7).

Direct Effects

Yields of Arizona cottontop and tall three-awns were much greater at 1 mile than at 1/4 or 5/8 mile with no marked difference between the two shorter distances. All perennial grasses, however, produced the least at 1/4 mile and the most at 1 mile.

Yields of annual grasses were not related to distance from water, and their effect resulted in the same relationship for the combined production of annual and perennial grasses.

Table 7. Differences between distances from water in herbage production, utilization of perennial grasses, and ground cover[a]

Plant class or species	Distance from water 1/4 mile	5/8 mile	1 mile	Sign. level (percent)
	HERBAGE PER ACRE (POUNDS)			
Arizona cottontop	15.68	17.48	27.19	1
Tall three-awns	6.61	5.24	12.06	1
Perennial grasses	38.25	49.65	66.24	1
Annual grasses	148.10	157.21	139.64	NS
Total grass	186.39	206.85	205.88	NS
	UTILIZATION (PERCENT)			
Arizona cottontop	53	49	48	NS
Tall three-awns	29	26	26	NS
Santa Rita three-awn	57	53	52	NS
Bush muhly	52	53	45	NS
All perennial grasses	45	41	40	5
	GROUND COVER (PERCENT)			
Perennial grasses	0.11	0.14	0.16	1
Burroweed	3.25	2.86	2.37	1
Mesquite	5.21	3.99	6.78	5
All shrubs	12.07	10.67	13.58	1

[a]Basal intercept of perennial grasses; crown intercept of shrubs

Utilization of all perennial grasses was lightest at 1 mile from water and heaviest at 1/4 mile as anticipated. However, differences in use between the 5/8- and 1-mile distances were not significant. Similar relationships were evident in some of the data for individual species, but in no case was the distance effect significant.

The basal intercept of perennial grasses was least at 1/4 mile. Differences between the 5/8- and 1-mile distances were relatively small although the greatest cover was at 1 mile. The relationship between distance and perennial grass cover appeared to be inversely related to average use.

The crown cover of burroweed was greater at 1/4 and 5/8 mile from water than at 1 mile. This suggests a positive correlation with grazing use and an inverse relationship with perennial grass cover.

Mesquite cover was greatest at 1 mile and least at 5/8 mile. The relationships of distance to cover of all shrubs was similar to that for mesquite. These distance effects are not readily explained.

Distance-by-Block Interactions

Distance-by-block interactions were found in the herbage yield data only for Arizona cottontop and tall threeawns (Appendix D). Arizona cottontop yields were lowest at

1/4 mile from water in block 1 and at 5/8 mile in block 2. The tall three-awns produced more than twice as much at the 1-mile distance in block 1 as under any other treatment combination. Distance from water had no consistent influence on the yield of herbage from tall three-awns in block 2, but the distance effect was strong in block 1. Both Arizona cottontop and tall three-awns yielded the least at 5/8 mile in block 2 and the most at one mile in block 1. These results are not readily explained by the data at hand. It is possible that the higher rainfall in block 1 coupled with less intensive use at 1 mile accounted for the relatively high yields of Arizona cottontop and tall three-awns for this combination but this hypothesis is not supported by the utilization data.

The utilization data showed that only bush muhly had a distance-by-block interaction (Appendix E). Utilization on bush muhly was significantly lighter at 1 mile in block 2 than for any other distance-by-block combination. However, in block 2, the degree of use on bush muhly decreased consistently with distance.

All distance-by-block interactions for ground cover data were significant (Appendix F). In block 1 perennial grass cover was lower at 1/4 mile than at 5/8 or 1 mile but perennial grass cover in block 2 was greater at 1 mile than at 1/4 or 5/8 mile. Burroweed cover in block 1 was least at 1 mile with no difference between the 1/4- and 5/8-mile distances whereas in block 2 the greatest cover was at 1/4 mile with no difference between the 5/8- and 1-mile positions. In block 1, mesquite intercept was much less at 5/8 mile than at 1/4 mile or 1 mile. In block 2, mesquite cover was less than half as great at 1/4 mile as at 5/8 mile or 1 mile. The mesquite cover was about three times as great on block 1 as on block 2. These general differences in mesquite cover were present when the study was initiated and cannot be attributed to treatments imposed in the study.

Total crown cover of the all shrubs class showed a similar distance-by-block interaction to that exhibited by mesquite. Thus, in block 1 the 5/8-mile distance had the lowest shrub cover while in block 2 the lowest shrub cover was at 1/4 mile. Total shrub cover differences among distances and blocks did not change appreciably during the study period.

Since the distance-by-block interactions are not readily explained it would appear that they were properly treated in Table 1 as a part of error b. These interactions have revealed some of the variability in the data and raised questions about causes for such inconsistencies.

SOIL-VEGETATION RELATIONSHIPS

Sites for sampling vegetation were so located that half of the plots had fine-textured subsoils and the other half had coarse-textured subsoils. The purpose of this arrangement was to determine any existing relationships between vegetation and these generalized soil groups and to determine whether responses of the vegetation to the grazing and mesquite control treatments were affected by soil differences.

Background Information

The influences of soil factors on the vegetation of semidesert ranges have received relatively little attention. Nevertheless, it is evident from the literature that soils exert profound effects on the course of vegetation development (Anderson 1956, Anderson and Fly 1955, Passey and Hugie 1962, Robocker 1958, and White 1961). Within a single pasture on the Santa Rita Experimental Range different kinds of vegetation are sometimes sharply delineated (Figure 4). Examination of the soil usually reveals marked differences between the two areas.

The soil pattern on the Santa Rita Experimental Range is very complex. A major difference that crosses over a number of soil types and that seems to have a bearing on the perennial grass cover is the relative amount of silt and

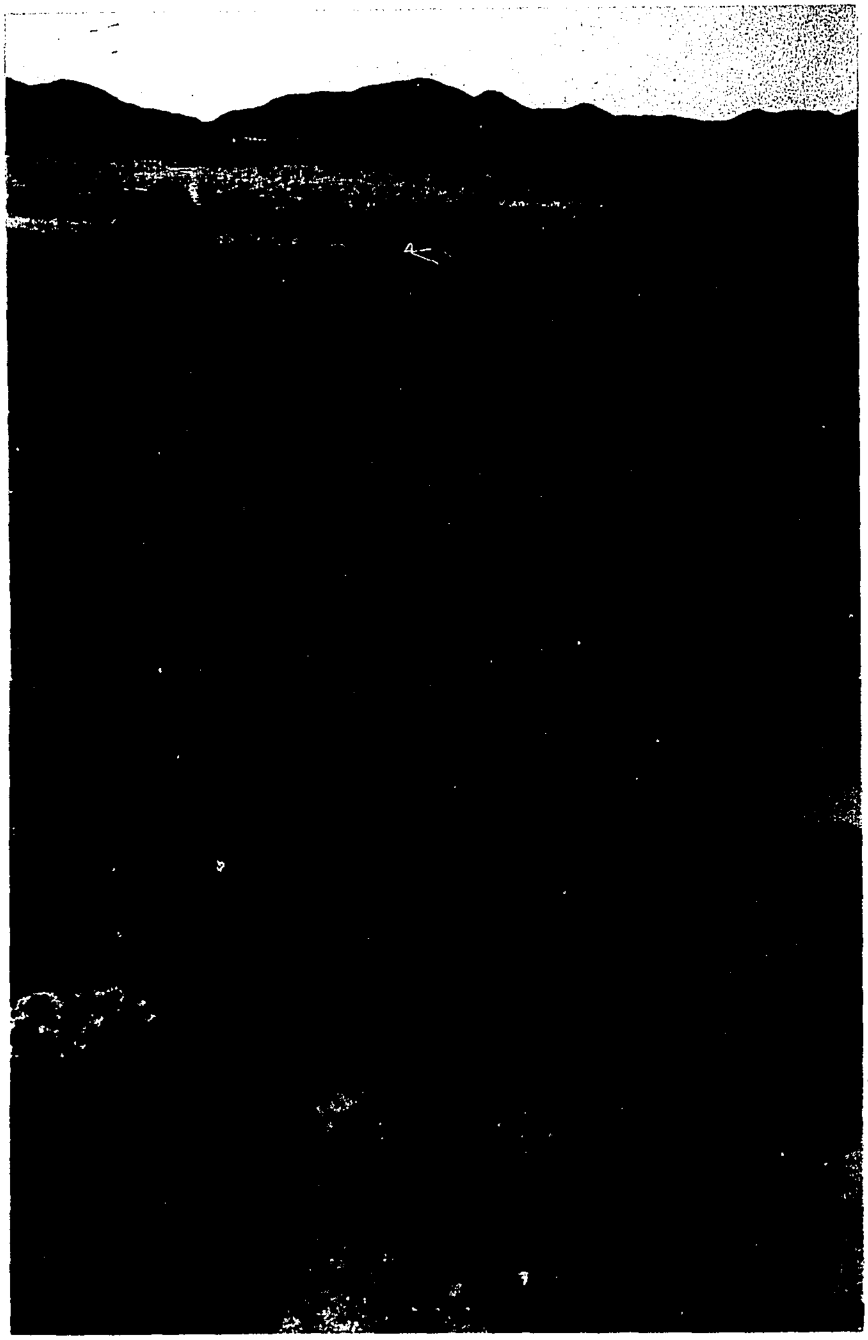

Fig. 4. An example of the influence of soil on vegetation.

Top: The vegetation on Whitehouse Gravelly Sandy Loam, a fine soil, is relatively free of mesquite, burroweed, and cactus. Bottom: Comoro Sandy Loam, a coarse soil, supports conspicuous stands of these species. (U.S.D.A., Forest Service photographs) clay in the subsoil. Under certain rainfall regimes, soils with silt or clay accumulation in the subsurface layers support more perennial grass than those with sandy or gravelly subsoils (U.S. Forest Service 1960).

The various soil types encountered on sample plots have arbitrarily been classified as "fine" or "coarse," depending on the texture of the subsoil. Both kinds of soil are relatively sandy at the surface. The "coarse" soils are relatively free of large rocks, tend to be more gray than red in color, have little profile development, and little or no clay accumulation in the subsoil. Comoro Coarse Sandy Loam, Tumacacori Coarse Sandy Loam, and Sonoita Sandy Loam are included in this group. The "fine" soils, on the other hand, are usually somewhat rocky, more red than gray in color, have marked profile development, and definite accumulations of clay in the subsoil. Whitehouse Coarse Sandy Loam, Continental Sandy Loam, Continental Gravelly Loam, and Tubac Sandy Loam are included in this group. These specific soil types have been described by Youngs et al. (1936).

Results of Soil Studies

Direct Effects

Yields of tall three-awns were the same on both soil types, but Arizona cottontop and all perennial grasses produced substantially more on the "fine" soil (Table 8).

Table 8. Differences between textures of subsoil in herbage production, utilization of perennial grasses, and ground cover[a]

Plant class or species	Texture of subsoil: Fine	Coarse	Sign. level (percent)
HERBAGE PER ACRE (POUNDS)			
Arizona cottontop	24.26	15.97	1
Tall three-awns	7.87	8.07	NS
All perennial grasses	58.15	44.61	5
Annual grasses	113.81	182.92	1
Total grass	171.96	227.45	1
UTILIZATION (PERCENT)			
Arizona cottontop	49	51	NS
Tall three-awns	24	30	5
Santa Rita three-awn	56	53	NS
Bush muhly	47	53	5
All perennial grasses	40	43	1
GROUND COVER (PERCENT)			
All perennial grasses	0.15	0.16	NS
Burroweed	3.02	2.63	NS
Mesquite	5.42	5.23	NS
All shrubs	11.77	12.44	NS

[a]Basal intercept of perennial grasses; crown intercept of shrubs

Yields of annual grasses and total grass were much greater on "coarse" soil.

Utilization was higher on coarse soil for tall three-awns, bush muhly, and all perennial grasses, but subsoil texture was not significantly related to use on Arizona cottontop or Santa Rita three-awn.

Differences in ground cover between soils were negligible.

Soil-by-Block Interactions

Yields of Arizona cottontop and all perennial grasses in block 1 were higher on fine than on coarse soil, but yields of these species were not affected by soil in block 2 (Table 9). Subsoil texture did not affect the yield of tall three-awns in either block.

Production of annual grasses in both blocks was higher on coarse soil, and the advantage of coarse soil apparently was greater in block 2 but the soil-by-block interaction was not significant. Thus, annual grasses behaved in a manner almost precisely opposite to that of the perennials. Because of the preponderance of annual grasses, total grass yields were also highest on coarse soil in block 2, but there were no significant differences among the other three soil-by-block combinations.

No significant soil-by-block interactions were found in the utilization data although inspection of the values in

Table 9. Differences between blocks and textures of subsoil in herbage production, utilization of perennial grasses, and ground cover[a]

Plant class or species	Texture of subsoil: Block 1 Fine	Block 1 Coarse	Block 2 Fine	Block 2 Coarse	Sign. level (percent)
HERBAGE PER ACRE (POUNDS)					
Arizona cottontop	36.94	20.90	11.59	11.04	1
Tall three-awns	11.74	11.84	3.99	4.30	NS
All perennial grasses	72.14	47.58	44.16	41.63	1
Annual grasses	90.68	122.33	136.94	243.31	NS
Total grass	162.83	169.97	181.09	284.94	5
UTILIZATION (PERCENT)					
Arizona cottontop	56	56	42	47	NS
Tall three-awns	29	35	19	25	NS
Santa Rita three-awn	60	56	52	49	NS
Bush muhly	51	55	42	50	NS
All perennial grasses	48	48	31	39	NS
GROUND COVER (PERCENT)					
All perennial grasses	0.20	0.13	0.10	0.12	1
Burroweed	4.35	3.88	1.70	1.37	NS
Mesquite	8.33	8.00	2.51	2.46	NS
All shrubs	15.20	16.22	8.34	8.67	NS

[a]Basal intercept of perennial grasses; crown intercept of shrubs

Table 9 suggests that block 2 was mainly responsible for the higher average utilization recorded on coarse soil for all perennial grasses (Table 8).

The basal intercept of perennial grasses in block 1 was greater on fine soil, but subsoil texture had no effect in block 2 (Table 9). There were no significant soil-by-block interactions in the crown intercept data for shrubs.

It has been pointed out that fine-textured subsoils produced more perennial grass herbage and supported a heavier grass cover in block 1, but differences between soils were negligible for these variables in block 2. It is suspected that the finer textured subsoils are advantageous in block 1 because the rainfall is higher than in block 2. Differences between blocks in the relative proportions of the fine and coarse soils that are made up by each soil series may also contribute to the soil-by-block interaction. For example, the fine soils in block 1 include more Whitehouse soil while those in block 2 include more Tubac. Observations indicate that the Tubac soils are less favorable than the Whitehouse soils for producing perennial grasses.

EFFECTS OF MESQUITE CONTROL

The use of paired plots with mesquite killed on one plot of each pair was included in the study for two reasons. First, most of the previous research at the Santa Rita Experimental Range on the effects of mesquite control had been done at higher elevations where the average annual rainfall exceeded 13 inches, and it was considered desirable to determine the effects of mesquite removal under more arid conditions. Second, general observations had indicated that the presence of mesquite on deteriorated semidesert range could prevent range improvement and it was considered likely that mesquite on the study area could prevent the expression of measurable effects from the season of grazing treatments.

Background Information

Many ranges that were almost brush-free 60 years ago now support moderate to dense stands of velvet mesquite, cactus, and burroweed (Figure 5). The mesquite stands vary greatly in density and in the degree to which better perennial grasses have been reduced. Increases in mesquite and burroweed were observed by several early workers on the Santa Rita Experimental Range (Griffiths 1910, Thornber 1910, Wooton 1916). However, parts of the range, especially at the lower elevations, already supported light to moderate stands of

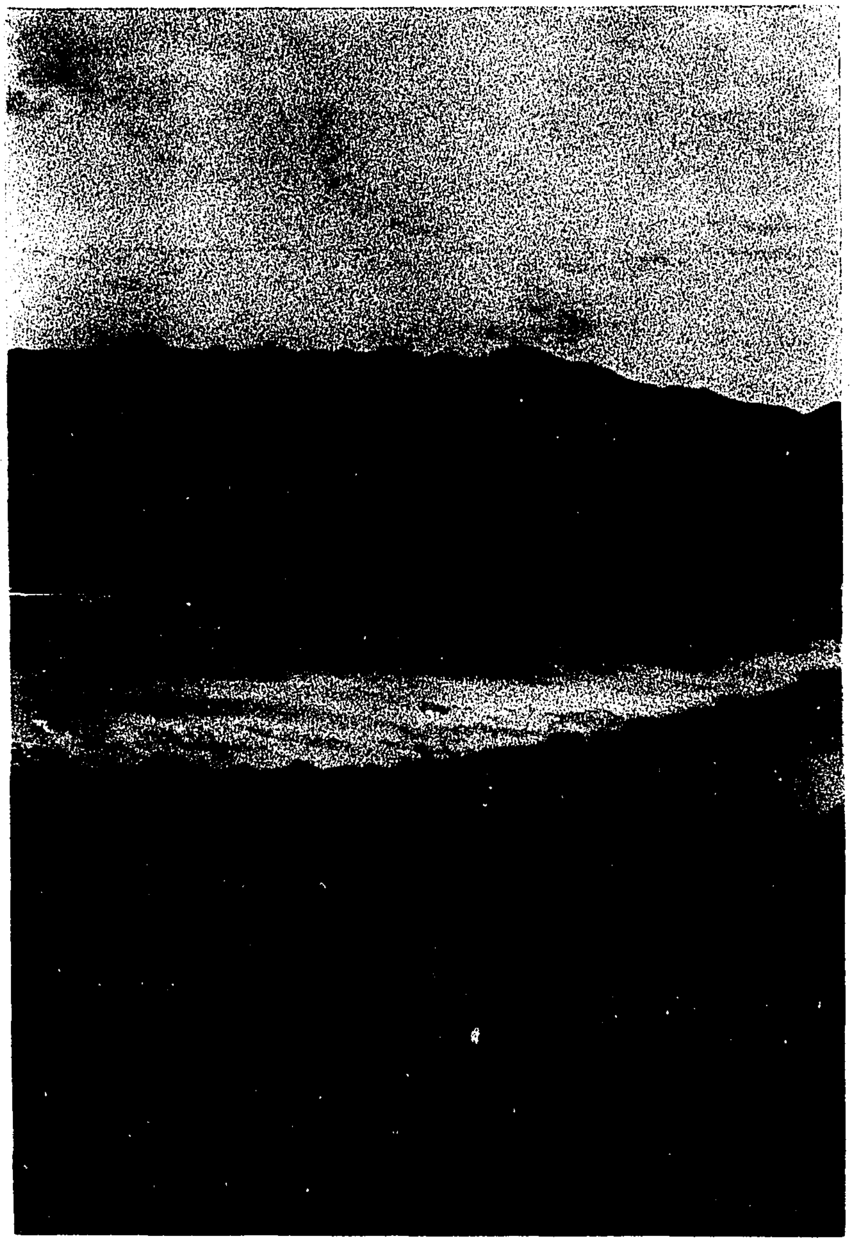

Fig. 5. Recent mesquite invasion on the upper part of the study area.

Top: Photograph taken in 1903 showing the relatively brush-free appearance of the range at that time. Bottom: Photograph taken from about the same location in March, 1964. (U.S.D.A., Forest Service photographs) mesquite and burroweed in 1903 (Griffiths 1904) (Figure 6).

The increase in mesquite has been attributed by numerous authors to the spread of mesquite seeds in the droppings of cattle, to a reduction in the perennial grass cover by overgrazing (Brown 1950, Haskell 1945), to a reduction in the frequency of range fires (Humphrey 1953, 1958; Humphrey and Mehrhoff 1958), and to combinations of these factors (Branscomb 1958, Glendening and Paulsen 1955, Parker 1949).

The invasion of semidesert rangelands by mesquite has been viewed with mixed emotions. Despite the dry climate, "cured" herbage of perennial grasses drops below minimum nutritional levels in protein, vitamin A, and sometimes phosphorus during extended periods of dry or cold weather. The foliage of mesquite helps overcome some of these specific shortages in the animal diet. Even in the driest years, mesquite leafs out in late April or in May, almost two months before summer growth is expected to start on the perennial grasses. On overgrazed ranges, where the grass is usually gone by late spring, the cattle can survive for a time on mesquite foliage. In years when there is a heavy crop of mesquite blooms and beans, the cattle will gain rapidly without grass. Many early stockmen considered the late spring grass shortages to be inevitable and were happy to have mesquite.

Parker and McGinnies (1941) reported that perennial grass density was inversely related to mesquite cover. Studies

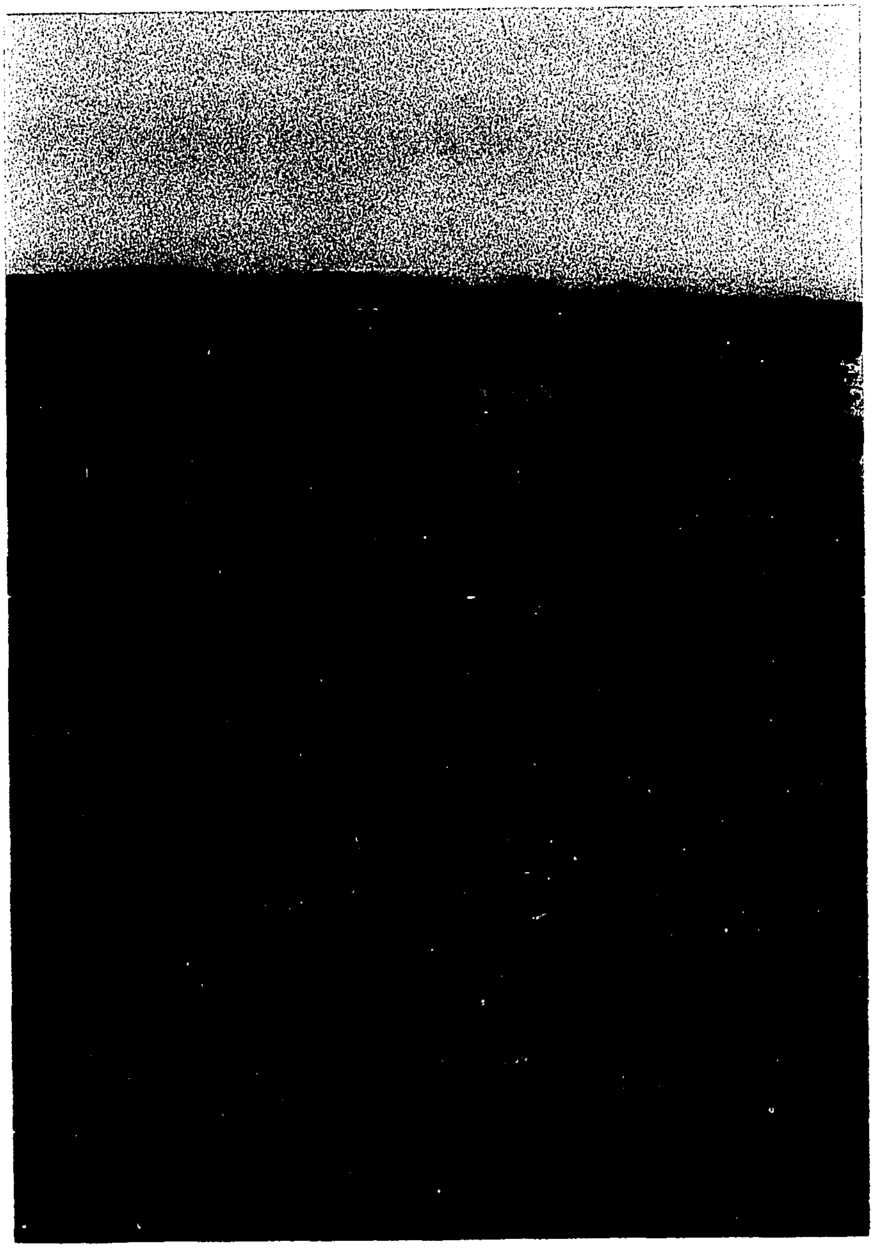

Fig. 6. Recent changes in vegetation on the lower part of the study area.

Top: Photograph taken in 1903 showing sparse grass cover and moderate stands of mesquite and burroweed. Bottom: Photograph taken in about the same location in March, 1964. The mesquite trees are larger, the burroweed stand looks about the same but there is much more annual grass herbage on the ground than in June, 1903. (U.S.D.A., Forest Service photographs) begun on the Santa Rita Experimental Range in 1940 showed that removing a stand of 80 mesquite per acre doubled grass production where the average annual rainfall was 13 inches (Parker and Martin 1952). In Texas, steer gains have been increased up to 53 percent by mesquite control (Fisher et al. 1959). Other studies in Arizona have indicated that as few as 25 trees per acre will cut grass production in half (Kincaid et al. 1959). Paulsen (1953) reported that soil conditions deteriorated under mesquite. Clements, Long and Martin (1940) concluded that mesquite removal is usually necessary for the improvement of semidesert ranges by reseeding or improved management. This conclusion is substantiated by photographs in Figure 7.

Results of Mesquite Control

Direct Effects

Yields of all species of perennial grasses, annual grasses, and total grass were significantly greater on the mesquite-free plots (Table 10). Among influences tested mesquite control showed the most consistent beneficial influence on herbage production.

Comparison of the relative amounts of annual grass in the total grass yield on mesquite-infested and mesquite-free plots showed that the mesquite-free plots produced relatively more annuals in dry years and more perennials in wet years

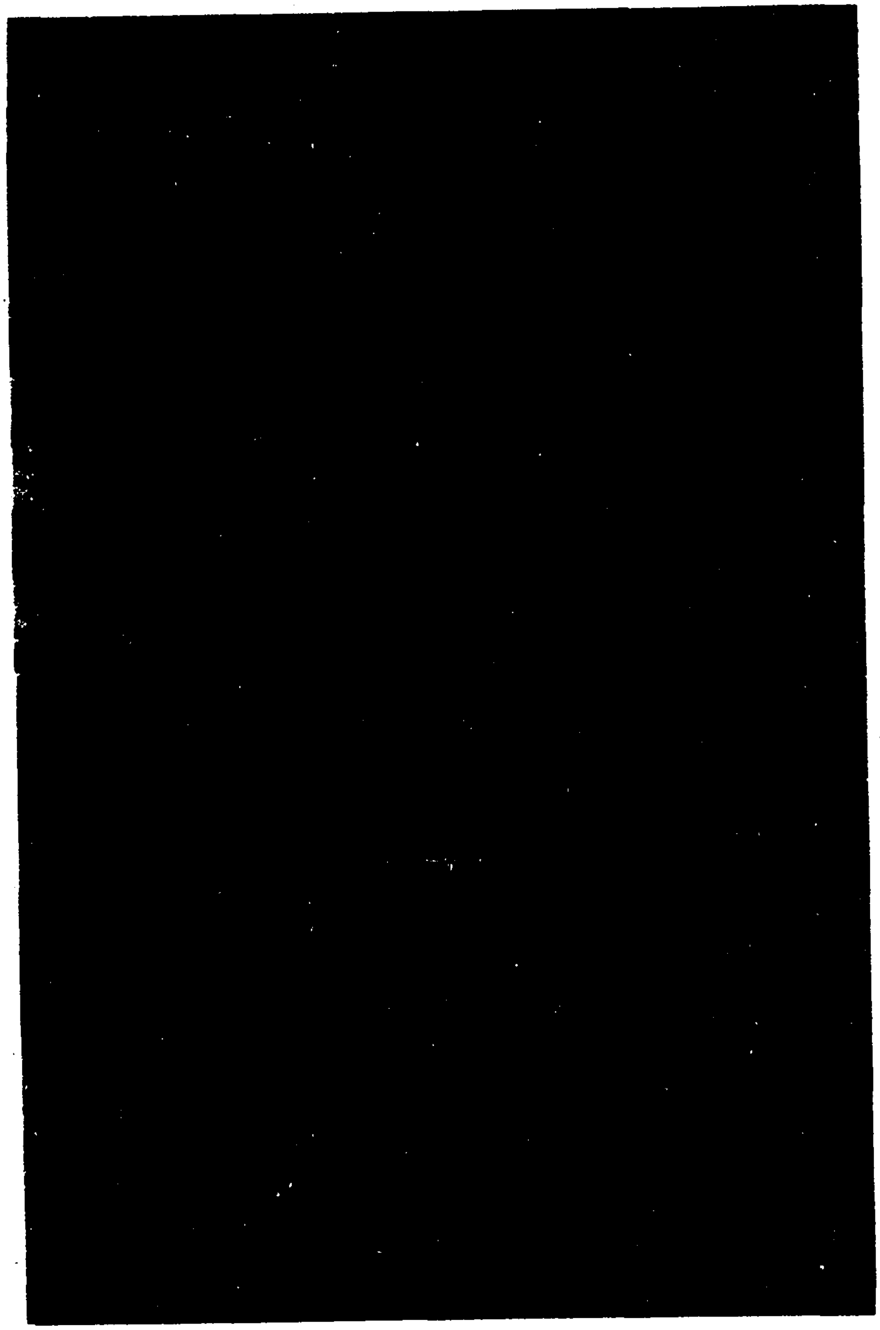

Fig. 7. Effects of protection from grazing and shrub control.

Top: Extremely sparse grass cover under a moderate stand of mesquite in March, 1964 after 48 years of protection from cattle grazing. Bottom: Somewhat better grass cover (March, 1964) on a nearby area where the mesquite was removed in 1935 and where continuous yearlong grazing by cattle prevailed until 1957 when the pasture was assigned to winter grazing. (U.S.D.A., Forest Service photographs)

Table 10. Differences due to killing mesquite in herbage production, utilization of perennial grasses, and ground cover[a]

Plant class or species	Condition of mesquite: Killed	Condition of mesquite: Alive	Sign. level (percent)
HERBAGE PER ACRE (POUNDS)			
Arizona cottontop	22.55	17.68	1
Tall three-awns	10.68	5.26	1
All perennial grasses	57.31	45.45	1
Annual grasses	175.66	120.97	1
Total grass	233.00	166.42	1
UTILIZATION (PERCENT)			
Arizona cottontop	48	53	5
Tall three-awns	25	29	5
Santa Rita three-awn	53	56	NS
Bush muhly	52	48	5
All perennial grasses	40	44	1
GROUND COVER (PERCENT)			
All perennial grasses	0.16	0.12	5
Burroweed	3.22	2.43	1
Mesquite	1.32	9.34	1
All shrubs	8.43	15.78	5

[a]Basal intercept of perennial grasses; crown intercept of shrubs

than was true on mesquite-infested plots (Figure 8). That mesquite-free plots produce higher grass yields in both low and high years is indicated by the positions of the ends of the two lines on the horizontal scale.

Utilization of all perennial grasses, tall three-awns, and Arizona cottontop was greater on the mesquite-infested plots (Table 10). Use of Santa Rita three-awn was not affected by mesquite control. Bush muhly, however, was more closely grazed where the mesquite was killed.

The basal cover of perennial grasses and the crown cover of burroweed were both greater where the mesquite was killed. Naturally the average crown cover of mesquite was greater where the mesquite was alive and, due to the preponderance of mesquite in the total shrub cover, the all shrub intercept was also greater on plots where the mesquite was not killed.

Mesquite-by-Block Interactions

The herbage production data contained several mesquite-by-block interactions (Table 11). Arizona cottontop and tall three-awns were more productive on mesquite-free plots in block 1, but mesquite control had little effect in block 2. Yields of annual grasses and total grass were also increased greatly by mesquite control in block 1, but only slightly in block 2. Total grass production on plots where the mesquite was killed was about the same in

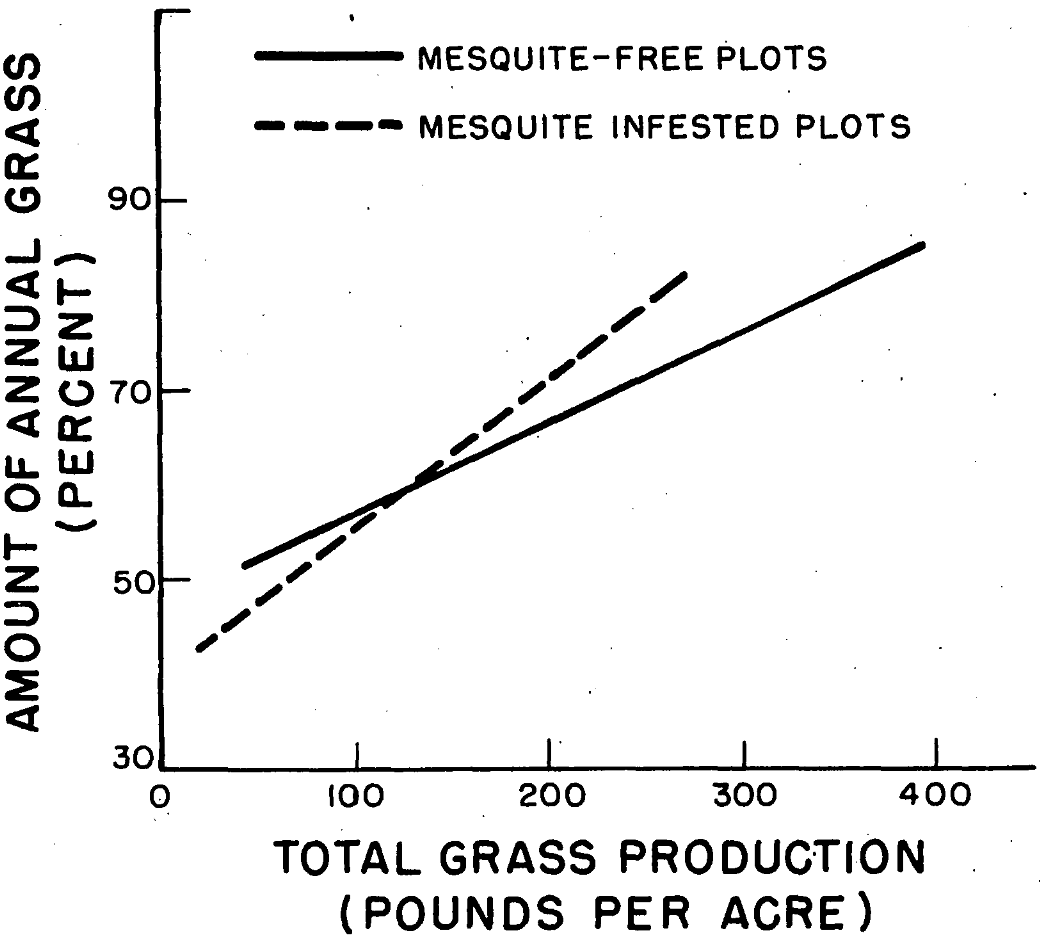

Fig. 8. Relative contribution of annual grasses to total herbage yield on mesquite-free and mesquite-infested plots.

53
8

Table 11. Differences between blocks and conditions of mesquite in herbage production, utilization of perennial grasses, and ground cover[a]

Plant class or species	Block 1 Mesquite Killed	Block 1 Mesquite Alive	Block 2 Mesquite Killed	Block 2 Mesquite Alive	Sign. level (percent)
			HERBAGE PER ACRE (POUNDS)		
Arizona cottontop	33.98	23.86	11.12	11.51	1
Tall three-awns	16.04	7.55	5.32	2.97	1
All perennial grasses	67.48	52.24	47.13	38.66	5
Annual grasses	153.30	59.72	198.02	182.23	1
Total grass	220.84	111.96	245.15	220.89	1
			UTILIZATION (PERCENT)		
Arizona cottontop	54	58	42	47	NS
Tall three-awns	28	36	22	22	5
Santa Rita three-awn	56	60	49	52	NS
Bush muhly	56	51	48	44	NS
All perennial grasses	47	51	32	37	NS
			GROUND COVER (PERCENT)		
All perennial grasses	0.18	0.15	0.13	0.09	NS
Burroweed	4.81	3.43	1.64	1.43	1
Mesquite	1.93	14.41	0.70	4.26	1
All shrubs	10.27	21.14	6.59	10.42	1

[a]Basal intercept of perennial grasses; crown intercept of shrubs

both blocks, but yields on plots where the mesquite was not killed were much higher in block 2. The fact that the amount of mesquite on the mesquite-infested plots was only one-third as great in block 2 as in block 1 probably accounts for the smaller response to mesquite control in block 2.

The only significant mesquite-by-block interaction on forage utilization was for the tall three-awns. For this group, utilization in block 1 was higher where mesquite was alive, but mesquite control had no apparent effect on utilization of tall three-awns in block 2.

Mesquite-by-block interactions were evident in all ground cover data except all perennial grasses. The increase in burroweed crown cover attributable to mesquite control was significant only in block 1.

The reduction in mesquite cover was much greater in block 1 than in block 2. The presence of mesquite cover where the mesquite was killed is explained by the fact that the first measurements were taken before the mesquite control treatment was applied and measurements for all 5 years are included in the block means. Because of the large contribution that mesquite makes to the total shrub cover, the interaction exhibited by total shrub cover was similar to that of mesquite alone.

Relative increases in herbage production after mesquite control were much greater in block 1 than in block 2 (Figure 9). In block 2, the difference in favor of mesquite

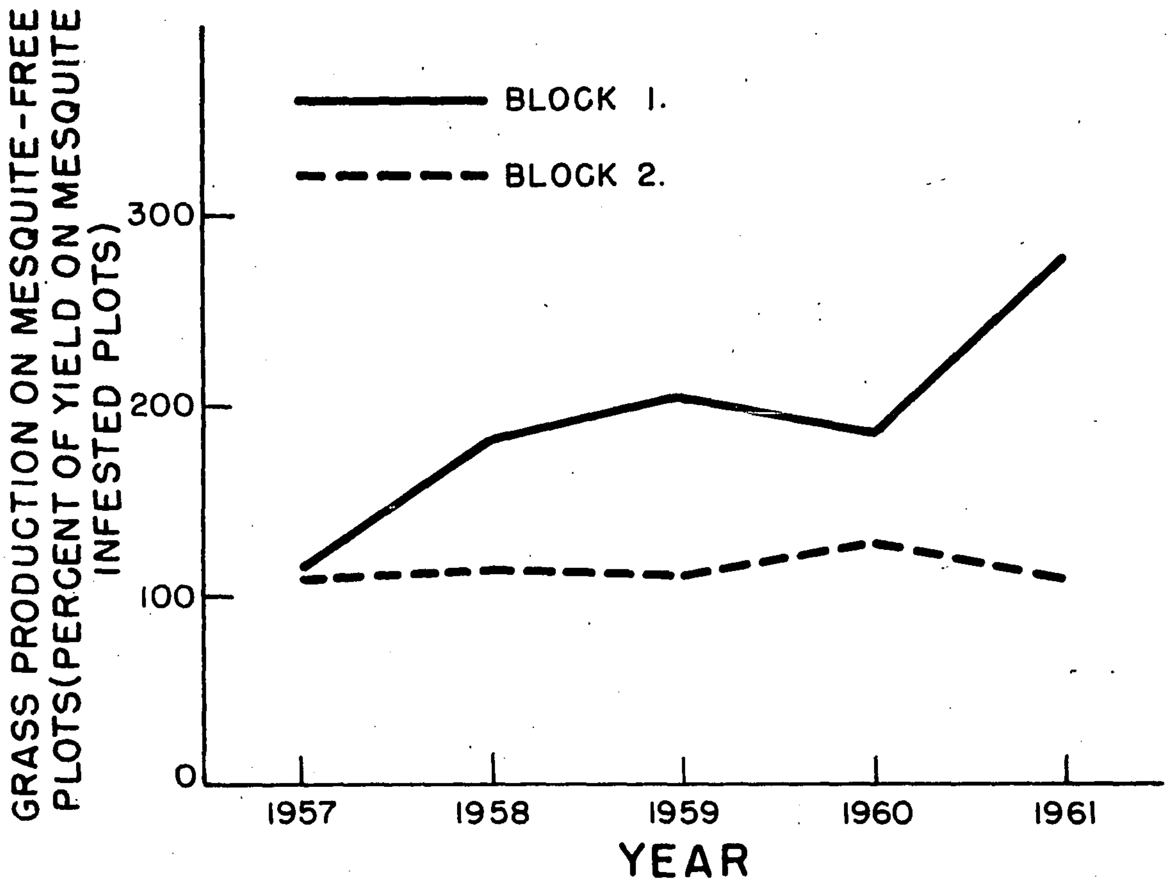

Fig. 9. Relative increases in grass yields after mesquite control in block 1 and block 2.

57
9

removal was about 10 percent starting in 1957 and remained about the same to the end of the study period. In block 1, however, there was a slight increase (13 percent) in 1957 followed by subsequent increases in later years until the yield on mesquite-free plots in 1961 was 277 percent of the yield on the mesquite-infested plots. This big difference between blocks resulted largely from initial differences in the mesquite stands. This means simply that the difference in the amount of mesquite on mesquite-killed and mesquite-alive plots was much greater in block 1 than in block 2. All mesquite-by-block interactions in herbage production and ground cover can be attributed primarily to this difference between blocks in the amount of mesquite cover.

SEASON OF GRAZING-VEGETATION RELATIONSHIPS

Winter, summer, and yearlong grazing were selected with the expectation that winter grazing would be less severe than yearlong grazing, and that summer grazing would be more severe in the effect of grazing on the perennial grasses. It was also anticipated that continuous application of these grazing treatments for several years would bring about measurable changes in the stands of perennial grasses. That continuous summer grazing or winter grazing do not constitute complete systems of grazing was recognized. This test was considered adequate, however, to determine whether a system of deferred or rotation grazing could help restore deteriorated semidesert range. The reasoning was that if continuous winter use did no good, and if continuous summer use did no harm, the prospects for improving the range by deferred or rotation grazing would be poor indeed. On the other hand, if winter grazing should prove beneficial and/or summer grazing detrimental, additional research on grazing systems would be justified.

Background Information

Periods of active growth for perennial grasses on semidesert range in southern Arizona are relatively short despite the long frost-free period. Growth during most of the year is limited by low soil moisture rather than by low temperature. Culley (1943) found that over 90 percent of the annual herbage yield of perennial grasses was made during the summer rainy season. The active growing period averaged 9 weeks, but periods as short as 5 weeks and as long as 12 weeks were recorded.

Less than 10 percent of the perennial grass herbage was produced from winter or spring rainfall. Active growth in the spring usually continued for a very short time and perennial grasses produced a substantial amount of spring forage only in exceptional years.

Partly because of mild short winters, yearlong grazing in the Southwest is traditional. Examples of range being maintained in satisfactory condition under yearlong use, however, are unusual.

Most investigations related to the effects of season of grazing on vegetation fall into one of the following groups: (1) clipping at various intensities, frequencies, or stages of growth, (2) intensity of grazing studies, and (3) comparisons between continuous grazing and some form of deferred or rotation system.

Clipping Studies

Many reports indicate that reductions in the density and yield of perennial grasses are related directly to the intensity, frequency, and duration of clipping (Branson 1956, Cook et al. 1958, Jameson 1963, Pond 1961, Ruby and Young 1953, Weaver and Hougen 1939). Albertson et al. (1953) reported that clipping stimulated top growth of blue grama (Bouteloua gracilis) and buffalo grass (Buchloe dactyloides) early in the study, but that continued close clipping was detrimental, especially in dry years. Jameson and Huss (1959) found that little bluestem (Andropogon scoparius) responded differently to clipping depending on whether leaves or stems were removed.

Stoddart (1946) concluded that damage to bluebunch wheatgrass (Agropyron spicatum) from herbage removal was inversely proportionate to herbage exposed to sunlight during the warm season as attained by (a) less close clipping, (b) clipping early enough to allow regrowth prior to summer drought, or (c) clipping late enough to allow food storage before herbage was removed. These results agree generally with those of Blaisdell and Pechanec (1949) and Pechanec (1949). Laude et al. (1957) concluded that herbage removal timed with growth characteristics of individual species offered a means for manipulation of vegetation.

Some of the more interesting clipping studies are those concerned with the effects of herbage removal on grass roots. Parker and Sampson (1931) reported that clipping stopped root growth. Crider (1955), in a series of carefully controlled clipping studies, found that removal of 50 percent or more of the top growth stopped root growth from 6 to 18 days. Repeated clippings stopped growth of roots from 25 to 45 days.

These results suggest that close grazing as frequently occurs on semidesert ranges during dry summers could severely reduce herbage production and stop root growth.

Grazing Intensity Studies

Grazing practices are important in range management, not only because they influence the vegetation, but because they provide opportunities to manipulate the vegetation at relatively little expense. Reed and Peterson (1961) found that major weather cycles exert the greatest influence on vegetation but that intensity of grazing modifies trends set by weather. Albertson et al. (1957) found that grasslands weakened by overgrazing during wet cycles were extremely sensitive to drought. Drought loss on heavily grazed range was nearly double that on moderately grazed ranges. Cook and Stoddart (1963) found that season of grazing was important and recommended winter grazing for the desert ranges of Utah. Clarke et al. (1943) found that fields grazed moderately in rotation suffered little deterioration from unfavorable climatic conditions. Reynolds (1954 and 1959) indicated that utilization on desert grasslands should average 35 to 55 percent in order to minimize damage to the vegetation during drought. Paulsen and Ares (1961 and 1962) reported that black grama range in New Mexico recovered from drought most rapidly on areas where utilization was less than 40 percent. However, severe reduction of the grass stand accompanied drought regardless of the method or intensity of grazing.

Deferred and Rotation Grazing Studies

Studies of plant succession in relation to grazing indicate that the most palatable plants are the first to suffer (Ellison 1959 and 1960, Herbel and Anderson 1959), and that the taller species are harmed more than the shorter grasses (Canfield 1948, Branson 1953, Neiland and Curtis, 1956).

Several workers have reported that deferred and rotation grazing systems offer no advantage in beef production over yearlong or seasonlong grazing, but that systems of grazing involving periods of rest did appear to benefit the vegetation (Hedrick 1958, Hormay 1961, Hubbard 1951, Hyder and Sawyer 1951, Smoliak 1960). Heady (1961) in a review of results from continuous vs. specialized grazing systems concluded that specialized grazing systems have no advantage over continuous grazing in livestock production, and that management factors other than system of grazing are more important in the production of livestock. On the other hand, Larin (1960) indicated that continuous grazing decreased the stands of the more palatable plants, and Dillon (1958) reported marked improvement in range productivity on a range in the Northwest after 7 years of rotation-deferred grazing.

Sampson (1951), in a review of pertinent literature, concluded that regional and local conditions have much to do with the results of rotation grazing; that rest during the growing season is especially beneficial to bunch grasses, but that sod grass ranges do not appear to be harmed by moderate seasonlong or continuous grazing. Rogler (1951) found that neither rotation grazing nor moderate continuous grazing was harmful in North Dakota. On the other hand, Mueggler (1950) found that heavy grazing during the spring growth period severely reduced forb and grass production in southern Idaho. Merrill (1954) found near Sonora, Texas, that a 4-month rest period in a 16-month grazing cycle improved the forage stand. And Frandsen (1950) concluded that it is very difficult to prevent range forage deterioration on seasonlong ranges, especially near water.

Possibilities for Improving Semidesert Ranges by Deferred or Rotation Grazing

In light of the foregoing review it appears that the main benefits that deferred or rotational grazing systems would offer on semidesert grass-shrub range would be improved distribution of grazing over the range area and among the forage plants. Yearlong grazing does not impose severe grazing pressure during the growing season over an entire range unit unless the stocking rate is excessive. This follows from the fact that 90 percent of the perennial grass herbage is produced in about 9 weeks and therefore less than one-fifth of the allowable grazing occurs during the growing season.

Heady (1964) feels that plant palatability and animal preference have been overrated as factors in grazing management. Even so it appears that the detrimental effects of yearlong grazing on semidesert ranges must be partly the result of preferences of cattle for certain areas and certain plants. It is entirely possible to remove only one-fifth of the allowable amount of forage from a range unit during the growing season and to do considerable damage in the process. This can happen if the portion of forage taken during the growing season consists mainly of preferred species from preferred parts of the range. Also, cattle usually regraze plants that have been grazed previously in preference to plants that have not been grazed before. This is not surprising because Smith (1960) found that the crude protein content of grass herbage was higher on clipped plants than on plants that had not been clipped and cattle seem to be able to select the more nutritious parts of vegetation that is available to them. On plants that have not been grazed previously, the new growth is mixed with a variable amount of old dead herbage. Thus cattle tend to regraze the same plants because they prefer new growth.

Under yearlong grazing, the processes set in motion by the preference of grazing animals tend to increase the distance between water and forage. Those parts of the range which should produce the most beef per unit area because they are close to water eventually produce almost nothing because the area has become denuded or because the better forage species have been replaced by undesirable plants.

Season of Grazing Results

Herbage Production

Total grass production was greatest on the units grazed yearlong and was about equal on summer- and winter-grazed range units (Table 12).

Since, as previously noted, the yearlong units in both blocks lie at higher elevations and receive more rainfall than do the seasonally grazed units, the higher grass yields on the yearlong pastures can be attributed largely to higher rainfall.

Perennial grass herbage yields were lowest on summer-grazed range and highest on yearlong range. Yields of Arizona cottontop were only 20 percent higher on yearlong than on winter range. The tall three-awns were no more productive on yearlong than on winter range. All perennial grasses, Arizona cottontop, and tall three-awns were less productive on summer-

Table 12. Differences between seasons of grazing in herbage production, utilization of perennial grasses, and ground cover[a]

Plant class or species	Season of grazing			Sign. level (percent)
	Winter	Summer	Yearlong	
	HERBAGE PER ACRE (POUNDS)			
Arizona cottontop	22.96	9.89	27.50	1
Tall three-awns	11.47	2.53	9.92	1
All perennial grasses	48.56	28.34	77.24	1
Annual grasses	135.43	142.93	166.58	NS
Total grass	184.00	171.27	243.86	5
	UTILIZATION (PERCENT)			
Arizona cottontop	54	48	48	NS
Tall three-awns	35	22	25	NS
Santa Rita three-awn	59	48	56	NS
Bush muhly	51	48	50	NS
All perennial grasses	46	40	39	NS
	GROUND COVER (PERCENT)			
All perennial grasses	0.10	0.09	0.22	1
Burroweed	2.51	3.27	2.71	1
Mesquite	3.84	7.74	4.40	1
All shrubs	9.41	15.03	11.88	1

[a]Basal intercept of perennial grasses; crown intercept of shrubs

grazed units than on winter range. Since the winter-grazed units received no more rainfall than those grazed in summer (Table 3), the higher yields of perennial grasses on the winter-grazed pastures are attributed to the grazing treatment. Yields of annual grasses were not affected by season of grazing.

Perennial grass yields were higher on winter range than on summer range in all years, but in every case the seasonally grazed units produced less than those grazed yearlong (Figure 10). Relative herbage production fluctuated more from year to year on winter-grazed range than on the summer-grazed units. Relative perennial grass production was much higher on the winter-grazed units in 1958 and 1960, but differences between the winter and summer units were small in the other three years. There appears to be no ready explanation for the relatively high grass yields on winter range in 1958 and 1960. The summer of 1958 was wet while that of 1960 was dry. Relative yields under the three grazing treatments at the end of 5 years stood in about the same positions as in the first year of measurement. In 1957, perennial grass yields on the winter and summer units were 38 percent and 28 percent, respectively, of those on the yearlong range. Comparable percentages in 1961 were 36 percent and 30 percent. Winter grazing did not permanently increase relative perennial grass production during the study period.

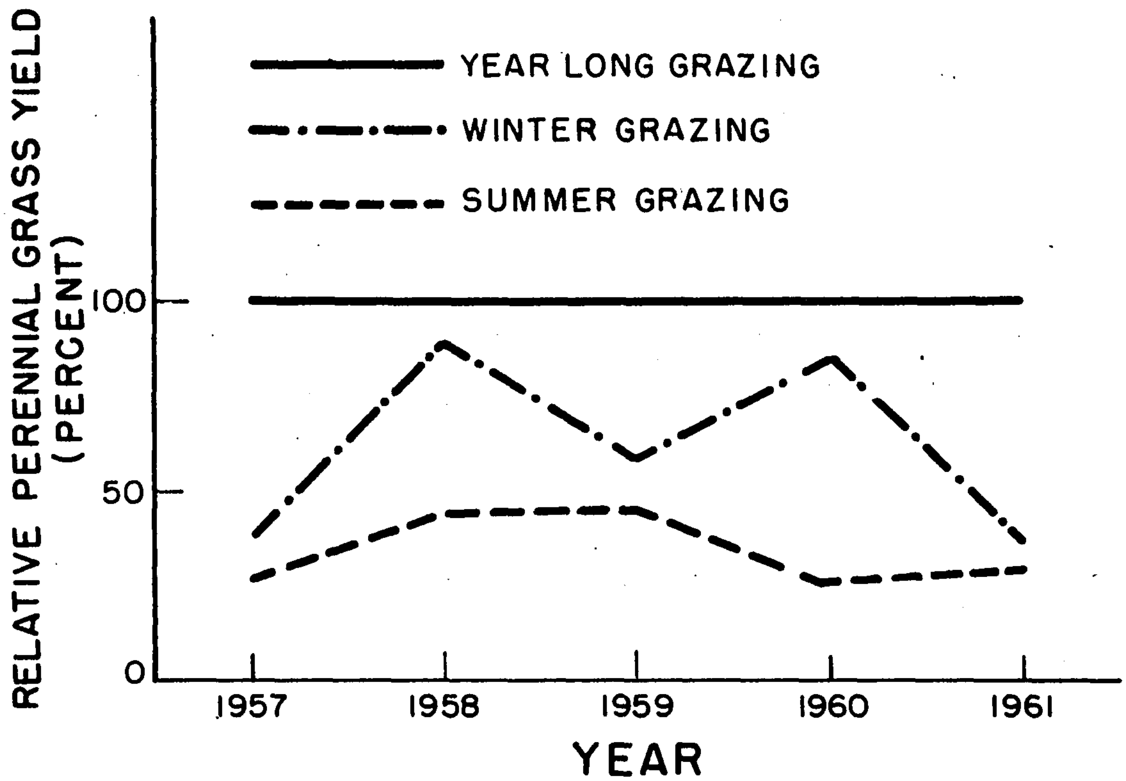

Fig. 10. Relative production of perennial grass herbage on yearlong, winter, and summer range for each year of the study period.

Utilization of Perennial Grasses

Minor differences in degree of use on perennial grasses were apparent among grazing seasons (Table 12), but these were not significant and they were not consistent from one species to another.

Ground Cover

Differences in grass cover parallel those of perennial grass yields (Table 12). The basal intercept of perennial grasses was about twice as great on yearlong range as on the seasonally grazed units and the difference between winter- and summer-grazed units was negligible.

All classes of shrub cover were highest on the summer-grazed units. Ranges grazed yearlong ranked second with only slightly more shrub cover than on winter range. To a large extent these differences in shrub cover among seasons of grazing existed from the outset and cannot be attributed to the treatment. It seems reasonable to assume, however, that the heavy shrub cover on the summer-grazed ranges may have influenced the production and cover of perennial grasses adversely. Consequently, the low yields of tall three-awns and of Arizona cottontop on summer range may have resulted partly from detrimental effects of the relatively high shrub cover.

Grazing-by-Block Interactions

The grazing-by-block interaction was significant for production of total grasses, annual grasses, all perennial grasses, and tall three-awns, but not for Arizona cottontop (Table 13). Yields of tall three-awns in block 1 were highest under winter use and lowest under summer use. In block 2 yields were highest under yearlong use, but yields under winter and summer use were about the same. Multiple range tests showed that Arizona cottontop produced less in block 1 under summer grazing than under winter or yearlong use, but there were no significant differences in block 2. Yields for all perennial grasses in block 1 were lowest under summer use with no difference between yearlong and winter use. In block 2, yields were highest under yearlong use and there was no difference between winter and summer use.

These results show that winter grazing increased perennial grass yields above yields on summer-grazed range in block 1 but not in block 2. Two factors probably contribute to this difference between blocks in response to season of grazing. First, the mesquite cover was greater on summer units in both blocks but the relative difference was greater in block 1. Second, average summer rainfall for the study period in block 1 was about 1/4 inch higher on the winter-grazed unit but in block 2 average summer rainfall on the winter-grazed unit was 1/2 inch lower than that of the summer

Table 13. Differences between blocks and seasons of grazing in herbage production and utilization of perennial grasses

Plant class or species	Block	Season of grazing: Winter	Summer	Yearlong	Sign. level (percent)
		HERBAGE PER ACRE (POUNDS)			
Arizona cottontop	1	35.78	12.98	37.99	NS
	2	10.14	6.80	17.00	
Tall three-awns	1	19.73	3.39	12.26	5
	2	3.20	1.68	7.57	
All perennial grasses	1	72.93	21.88	84.78	1
	2	24.20	34.79	69.69	
Annual grasses	1	100.62	134.99	83.92	5
	2	170.25	150.88	249.25	
Total grass	1	173.54	156.87	168.78	5
	2	194.45	185.67	318.94	
		UTILIZATION (PERCENT)			
Arizona cottontop	1	61	54	54	NS
	2	46	43	42	
Tall three-awns	1	35	29	32	NS
	2	34	13	19	
Santa Rita three-awn	1	63	53	59	NS
	2	56	42	55	
Bush muhly	1	52	62	46	1
	2	51	33	55	
All perennial grasses	1	50	49	47	NS
	2	42	31	31	

unit. Both of these factors would tend to produce a greater apparent advantage for winter grazing in block 1 than in block 2.

In block 2, annual grasses produced the most under yearlong grazing. In block 1, they produced the least under yearlong grazing. Total grass yield was substantially greater in the yearlong pasture of block 2 than for any other unit.

Bush muhly was the only perennial grass that showed a grazing-by-block interaction in utilization (Table 13). Utilization on bush muhly was lighter in the summer-grazed unit of block 2 than any other and was heaviest in the summer unit of block 1.

All classes of ground cover data showed grazing-by-block interactions (Table 14). Perennial grass cover was highest in both blocks under yearlong grazing. The lowest perennial grass cover was on the winter-grazed unit of block 2, the unit with the lowest rainfall.

Burroweed crown cover was higher under all grazing treatments in block 1 than in block 2. In block 2, the summer unit supported the most burroweed.

Mesquite cover was highest in the summer-grazed unit of block 1 and second in the yearlong unit of the same block. In block 2, the summer-grazed unit had more mesquite than the yearlong and winter units. The light mesquite cover in the yearlong unit of block 2 may account for the high average total grass yield in that pasture.

Table 14. Differences between blocks and seasons of grazing in ground cover[a]

Plant class or species	Block	Season of grazing: Winter	Summer	Yearlong	Sign. level
		Percent			
All perennial grasses	1	0.15	0.09	0.25	5
	2	0.05	0.10	0.19	
Burroweed	1	3.86	4.29	4.20	5
	2	1.16	2.24	1.22	
Mesquite	1	5.44	11.24	7.83	1
	2	2.24	4.24	0.97	
All shrubs	1	12.28	18.68	16.16	5
	2	6.54	11.37	7.60	

[a]Basal intercept of perennial grasses; crown intercept of shrubs

It is difficult to generalize from the foregoing array of grazing-by-block interactions. In both blocks the yearlong units received more rainfall than the summer and winter units and should have supported more vegetation. Conversely, the winter-grazed unit of block 2 received the least rainfall of any unit in the study and should have supported less vegetation than any other unit. The basal intercept data for perennial grasses conformed to both expectations, but yield data for grasses contained several exceptions.

The shrub intercept measurements did not conform to the rainfall pattern, but were highest on summer-grazed pastures. Herbage yields were lowest on the summer-grazed units. These data suggest that an inverse relationship existed between shrub cover and grass yield. The crown cover of mesquite was least and the total grass yield was highest on the yearlong unit of block 2. At the other extreme, mesquite cover was greatest and total grass production was least on the summer-grazed unit of block 1. Plotting mesquite cover against herbage production and perennial grass cover for each of the six study units showed that annual grass yields were inversely related to mesquite cover, but that yields of perennial grasses were more closely related (r. = 0.94) to grass cover (Figure 11).

The consistency with which yields of Arizona cottontop and tall three-awns on winter range exceeded those on summer

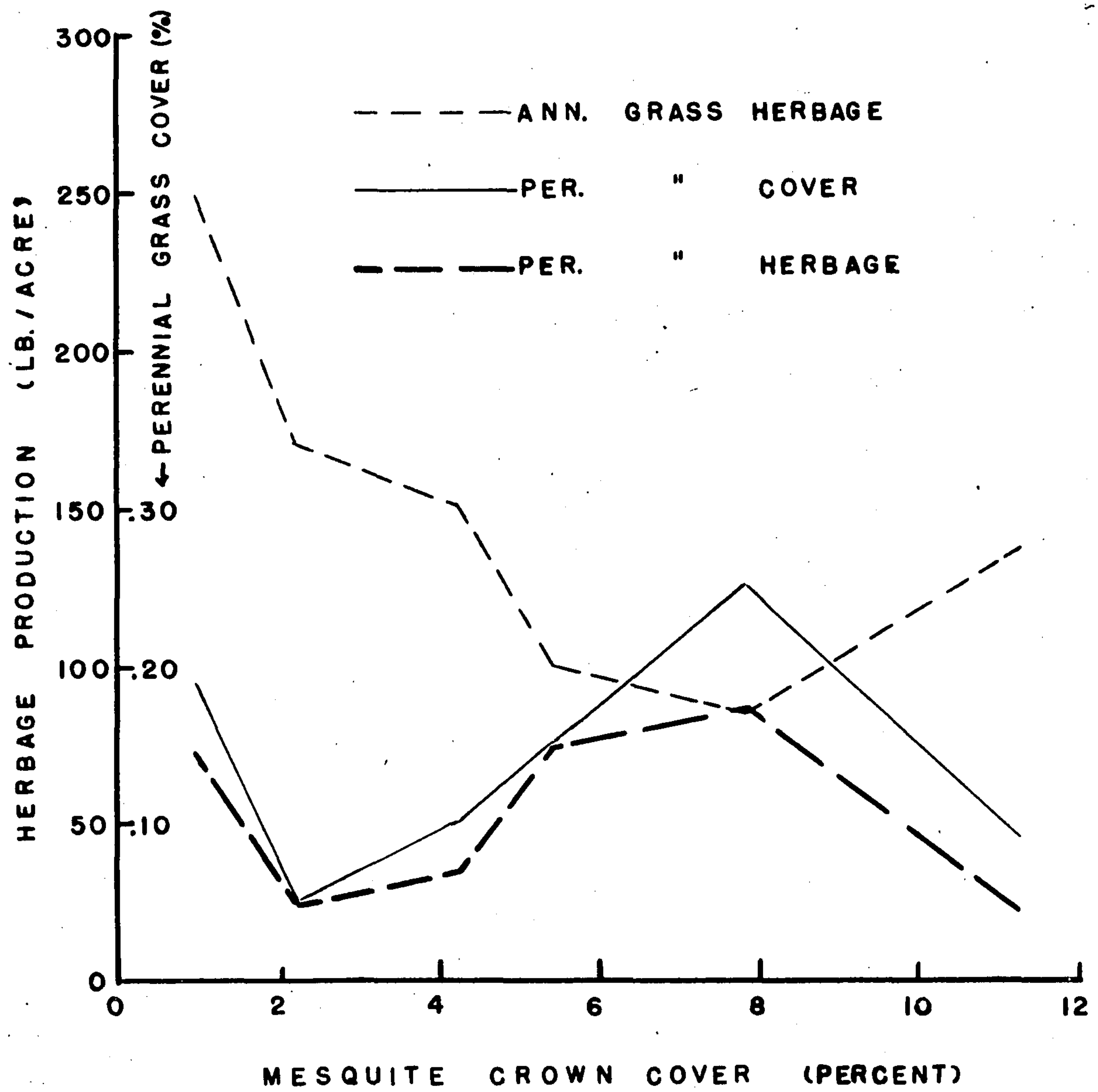

Figure 11. Effects of mesquite crown cover on herbage yields of annual and perennial grasses and on perennial grass cover.

range in both blocks suggests that winter grazing is superior to summer grazing even though the grazing effect is largely obscured by the effects of differences in rainfall and mesquite cover.

EFFECTS OF TREATMENT INTERACTIONS

All first order interactions were tabulated and examined but only a few were significant. To avoid unnecessary interruptions in the text, these tables are included as appendices G through R.

Differences Between Soils at 1/4, 5/8, and 1 Mile from Water

The only soil-by-distance interaction was found in the utilization data for bush muhly (Appendix G and H). Use of bush muhly was lightest (38 percent) at 1 mile from water on fine soil. Differences in utilization of bush muhly among other combinations were not significant. Data obtained in the study did not adequately explain this interaction. The distance effect is reasonable, but the cause of the soil effect is obscure. It may be related to differences between soils in the density and species composition of the grass stand and to differences in palatability among grass species.

Effects of Mesquite Control at 1/4, 5/8, and 1 Mile from Water

The only mesquite-by-distance interaction was in the production data for all perennial grasses (Appendix I and J).

Perennial grass production increased with distance both with and without mesquite control. However, mesquite control produced significant increases in perennial grass yield at 1/4 and 5/8 mile, but not at 1 mile. Similarly, the ground cover of perennial grasses was not affected by mesquite control at 1 mile, but the mesquite-free plots supported more perennial grass cover at 1/4 and 5/8 mile. Since the relative reduction in mesquite cover was just as great at 1 mile as it was closer to water, it is suspected that lighter utilization at 1 mile may account for the relatively high cover and yield of perennial grasses on the mesquite-infested plots at 1 mile from water. Although these differences in grass cover were not significant, they were correlated ($r = 0.94$) with perennial grass yields. The relatively high yield of perennial grasses at 1 mile where the crown cover of mesquite was greatest indicates that factors associated with distance from water affected perennial grass yields almost as strongly as did the presence of mesquite.

Effects of Mesquite Control on Fine- and Coarse-Textured Subsoils

Significant mesquite-by-soil interactions were found only in the herbage production and ground cover data (Appendix K). Arizona cottontop and all perennial grasses responded to mesquite control on fine soil, but not on coarse soil. Tall three-awns responded to mesquite control on both soils, but the response was greater on fine soil. The difference between soils in the response of perennial grasses to mesquite control was not the result of differences between soils in the amount of mesquite cover. It is assumed that the difference was due to some property of the fine soils that made them more favorable for the production of perennial grasses.

Burroweed cover was greater on mesquite-killed plots on both soils, but the response was greater on fine-textured subsoils. This response was very similar to that of yields for tall three-awns. The crown cover of burroweed, however, was higher on the mesquite-killed plots on fine soil than on comparable plots on coarse soil. Differences between soils on mesquite-alive plots were not significant. As in the case of perennial grasses, it is suspected that the fine soils were in some way more favorable than coarse soils for growing burroweed in the absence of mesquite.

Effects of Season of Grazing at 1/4, 5/8, and 1 Mile from Water

Significant grazing-by-distance interactions were evident only in the herbage production and ground cover data (Appendix L, M, and N).

Tall three-awns produced the most at 1 mile on winter-grazed range. None of the other differences was significant for this species. Thus, for tall three-awns, winter grazing was best at 1-mile distance, but not at 1/4 or 5/8 mile. Utilization of tall three-awns was heavier under winter grazing than under summer or yearlong grazing at 1/4 and 5/8 mile. This may explain why yields of tall three-awns did not increase near water under winter use.

Arizona cottontop also produced the most on winter range at 1 mile. Intermediate yields of Arizona cottontop were produced at the 1/4- and 5/8-mile distances on yearlong range with lower yields at all other combinations. Yield differences for Arizona cottontop did not appear to be so clearly related to differences in utilization as was the case for tall three-awns.

High yields for all perennial grasses were obtained at 5/8 mile and 1 mile from water on yearlong ranges and at 1 mile on winter range, with all other combinations somewhat lower. The lowest perennial grass yields were on summer range at 1/4 mile as expected.

The basal intercept averages for perennial grasses at 5/8 mile and 1 mile on yearlong range were over twice as high as for any other combination. These high values probably are the result of higher average rainfall coupled with lower average utilization acting over a period of many years.

The crown cover of burroweed was highest at 5/8 mile on summer range and at 1/4 mile on yearlong range. The lowest value was at 1 mile on yearlong range. These represent departures from the average effects of distance and season of grazing which show that burroweed cover is greatest at 1/4 mile from water and under summer grazing. The reason for this interaction is not apparent.

Data collected during the study did not entirely explain the grazing-by-distance interactions. It would be reasonable to attribute the higher yields of perennial grasses at 1 mile to lighter utilization. The utilization data do show a decrease in intensity of grazing with increasing distance, but the distance effect on utilization was not significant for any species. Still, differences in use probably contribute to the interactions involving perennial grass cover and production.

Effects of Season of Grazing on Fine and Coarse Soils

Herbage yield data showed significant grazing-by-soil interactions only for Arizona cottontop and total grass (Appendix O). Yields of Arizona cottontop under yearlong grazing were much higher on fine-textured subsoils. Soil type had no effects on the yields of Arizona cottontop on the winter- and summer-grazed units. It is suspected that the fine soils were advantageous for Arizona cottontop on yearlong range because the yearlong units received more rainfall.

Yields of total grass herbage on the yearlong units were the same on both soil types. On the winter- and summer-grazed units yields were significantly higher on the coarse-textured soil. Since total grass production was determined largely by the yields of annual grasses the advantage of coarse soil was due to the superior production of annual grasses on coarse soil under the lower rainfall regime of the seasonally grazed units.

On winter range, Santa Rita three-awn was grazed heavier on the fine soil, but on yearlong range use was heavier on coarse soil (Appendix O). The soil effect was not significant on summer-grazed range.

Utilization of bush muhly was higher on coarse soil under winter and summer grazing. Under yearlong grazing utilization of bush muhly was higher on fine soil, but the difference was not significant.

Utilization of Arizona cottontop on coarse soil was about the same under all seasons of grazing. Utilization on winter range was heavier on fine soils, but on summer and yearlong range Arizona cottontop was more heavily grazed on coarse soil.

It is suspected that most differences in utilization that were not clearly related to distance from water or season of grazing resulted from differences in the density and species composition of the perennial grass stands.

The only ground cover measurements exhibiting a grazing-by-soil interaction were those for the perennial grasses (Appendix P). The basal intercept for the perennial grasses on the yearlong unit was higher on fine-textured soil. And the season of grazing effect was significant only on fine soil. Differences between soils were negligible on winter and summer range. Here again it appears that the higher rainfall on yearlong range resulted in an increase only on the fine-textured soil.

Effects of Mesquite Control Under Winter, Summer, and Yearlong Grazing

The grazing-by-mesquite control interaction was evident in the production data for tall three-awns and for all perennial grasses and in ground cover data for mesquite and all shrubs (Appendix Q and R).

Mesquite control increased the yields of tall three-awns and all perennial grasses by significant amounts only on the winter and yearlong grazing units. Yields of tall three-awns and all perennial grasses were lowest on the summer-grazed plots on both mesquite treatments. This suggests that the detrimental effects of summer grazing may have kept the tall three-awns and all perennial grasses from responding to mesquite control on the summer-grazed pastures.

No grazing-by-mesquite interactions were evident in the utilization data.

The line intercept data for all shrubs combined showed grazing-by-mesquite interactions that were related strongly to those of mesquite cover. This was expected because mesquite made up a major part of the total shrub intercept. The total shrub intercept was greatest on the summer units where mesquite was alive and second on the yearlong units on mesquite-infested plots. Differences in shrub cover among grazing seasons were relatively small on the mesquite-free plots.

Mesquite control reduced the crown cover of mesquite and of all shrubs under all seasons of grazing. On mesquite-infested plots, mesquite cover was heaviest on summer range and was about equal on winter and yearlong range. All shrub cover on mesquite-infested plots not only was highest on summer range, but also was higher on yearlong than on winter range. Almost all changes in total shrub cover during the study period could be attributed to changes in mesquite or burroweed.

Higher Order Interactions

Several of the higher order interactions were significant. The grazing-by-distance-by-mesquite interaction was significant for 9 of the 14 variables tested, the grazing-by-soil-by-mesquite for 4, the distance-by-soil-by-mesquite for 5, and the grazing-by-distance-by-soil-by-mesquite for 4. It is difficult to draw practical conclusions from these complex interactions and the possibility exists that some of these interactions were apparent only and were due to coincidence. Because of these problems and hazards, no attempt has been made to interpret the three-and four-factor interactions as such. Instead, the three-way table of the grazing-by-distance--by-mesquite interaction has been used as a classification device for exploring some of the relationships among sets of data taken.

If the yields of perennial grass herbage from this three-way classification are plotted against all shrub intercept data for the same table, a visual pattern emerges (Figure 12). The pertinent relationships are indicated by the size, shape, and position of six triangles. Each triangle is formed by plotting the perennial grass yield against the all shrub intercept for each distance for a given grazing-by-mesquite combination.

The vertical spans of the triangles show the range in perennial grass production for the particular grazing-by-mesquite combination. Since the vertices of the triangles represent the values obtained at the three distances from water, the size and orientation of the triangles reveals the distance effect. No fixed order existed among distances with respect to perennial grass yields. Yields at 1-mile distance were highest in only three cases but two of these were on winter-grazed range. Evidently distance from water had greater effects on perennial grass yields on winter range than on summer or yearlong range. Yields at 1/4 mile were lowest in 5 of the 6 triangles. The 5/8-mile distance was high in three cases, low in one, and intermediate in two.

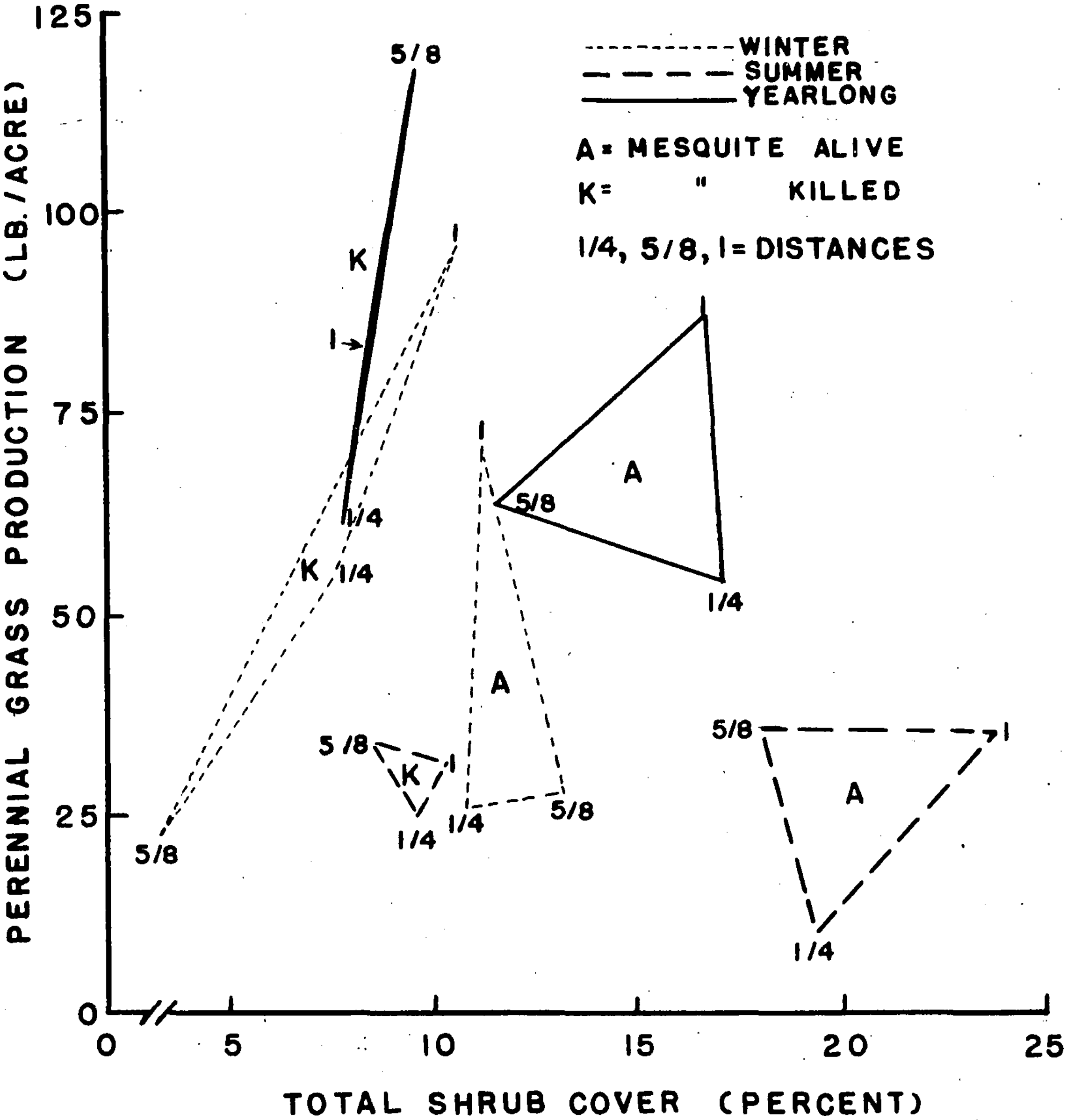

Fig. 12. Relation between shrub cover and yield of perennial grass herbage.

This mixed response shows quite clearly that the distance effect was strong between the 5/8- and 1-mile distances only on winter range, but that the 1/4-mile distance was consistently low in perennial grass yield. The much reduced size of the triangle for mesquite-killed plots under summer grazing shows that differences among distances in grass production and shrub cover were both very small for that treatment combination.

The three triangles toward the right-hand side of the figure represent the mesquite-alive plots. These three triangles tend to be equilateral and their orientation suggests that there is little correlation between the amount of shrub intercept and the yield of perennial grasses. The mesquite-free plots on summer-grazed range show about the same configuration and orientation. The triangles for mesquite-free plots on winter and yearlong range, however, are almost linear and are slanted in a way that suggests a positive correlation between shrub cover and perennial grass yield.

Another feature illustrated by this figure is that removing the mesquite had little effect on perennial grass production on the summer-grazed range. This is indicated by the fact that the summer-alive and summer-killed triangles are much closer together on the vertical scale than on the horizontal. By contrast, mesquite-killed and mesquite-alive plots on the winter and yearlong units were closer together on the horizontal scale, but farther apart on the vertical.

GENERAL CONCLUSION

The results presented in this dissertation constitute a midpoint evaluation in a planned 10-year study. The main plot (season of grazing) effects were not significant and with only two replications they are not apt to become so in a reasonable period of time. All of the subplot treatment effects (distance, soil, and mesquite) were significant for certain variables and provided bases for drawing tentative conclusions about these effects and their interactions. The block and year effects and their interactions reveal something of the magnitude of environmental variability in this type of study. Much of the information brought out in this study will be valuable in planning future experiments even though it does not provide a basis for making practical recommendations to ranchers. Some of the tentative conclusions should be strengthened by carrying the study through another 5-year period.

SUMMARY

A 5-year study of factors affecting vegetation change was started in 1957 on 28,000 acres of semidesert cattle range in southern Arizona. The influences studied were winter, summer, and yearlong grazing, mesquite removal, texture of subsoil, distance from water, and year-to-year variation. Effects were measured by changes in herbage production of annual and perennial grasses, utilization of perennial grasses, and ground cover of perennial grasses and shrubs.

The design was a split-split-split plot with one replication of the three seasons of grazing in each of two blocks. The second level of the analysis included the within-pasture distance and soil effects; with the mesquite control treatments constituting the third split. Year effects were considered random and were included with the block and grazing season effects in the major plot portion of the analysis.

The year immediately preceding the start of the study (1956) was extremely dry. The study period 1957-1961 included some unusual rainfall events, but it could not be classed as either a wet or a dry period. The outstanding rainfall event was the unusually high rainfall in both spring and summer of 1958. This one favorable year raised perennial grass yields from their lowest recorded level of the study period in 1957 to their highest value one year later. Perennial grass cover

also was highest in 1958. The performance of perennial grasses in 1958 showed that recovery of semidesert ranges could be rapid and that extremes in rainfall may have more influence than any other single factor on short-term changes in forage conditions on semidesert range.

Burroweed crown cover changed greatly from year to year, increasing in years with high winter or spring precipitation and decreasing when cool-season precipitation was low.

Several differences among the study pastures were apparent at the outset. Block 1 received more rainfall and supported more perennial grasses and more shrubs than block 2. The yearlong units in both blocks lay at higher elevations and received more rainfall than the seasonally grazed ranges.

Average total grass herbage production for all treatments over the 5-year period was about 200 pounds per acre and ranged from a low of 54 pounds per acre in 1957 to a high of 334 pounds in 1959. Annual grasses made up three-fourths of the average grass yield and year-to-year variations in yield were much greater for annual grasses than for perennial grasses.

Average total grass yields in block 1 and block 2 were 166 and 233 pounds per acre, respectively. However, the advantage recorded for block 2 was made up entirely of annuals since block 1 produced 40 percent more perennial grass herbage than did block 2. Average utilization on perennial grasses was 48 percent in block 1 and 35 percent in block 2.

Perennial grass cover and production increased and utilization decreased with increasing distance from water, but yields of annual grasses and total grass were not affected. Burroweed crown cover was greatest at 1/4 mile and least at 1 mile from water. Crown cover of mesquite and all shrubs was greatest at 1 mile and least at 5/8 mile.

Annual grasses were more productive on coarse-textured subsoils, but perennial grasses produced higher yields on fine-textured subsoils. Utilization of tall three-awns and bush muhly were higher on the coarse soils, but utilization of other species was not affected significantly by soil. There were no significant differences in ground cover between soils.

Mesquite control increased perennial grass yields by 26 percent and annual grasses by 45 percent. Mesquite control also increased utilization of bush muhly, but average utilization of all other species of perennial grasses was higher on plots where the mesquite was alive. Ground cover of perennial grasses and burroweed was higher on mesquite-free plots, but plots with live mesquite supported a higher total shrub cover.

Perennial grass production was highest under yearlong grazing, lowest under summer grazing, and intermediate under winter grazing. The high yields under yearlong use were due partly to higher rainfall which cannot be separated from the grazing effect. However, since the summer-grazed units enjoyed a slight rainfall advantage, the higher yields on winter range showed that winter grazing was more beneficial to perennial grass than summer grazing.

Annual grass yields were not significantly affected by season of grazing.

Perennial grass cover was highest on yearlong range, but all classes of shrub cover were greatest on summer-grazed range. These differences are assumed to be more closely related to differences in rainfall and use history than to effects of grazing during the study period.

Interaction studies showed that the effects of mesquite control on grass production were more pronounced than for any other treatment. However, because the mesquite cover was greater in block 1, mesquite control resulted in much greater increases in grass production in block 1 than in block 2. Mesquite control increased perennial grass production on fine soil but not on coarse soil but increases in annual grass yields were pronounced on both soils.

Interactions between distance from water and other factors showed that differences in perennial grass production between fine and coarse soils, between mesquite-killed and mesquite-alive plots, and between winter and yearlong grazing were relatively great at 1/4 and 5/8 mile, but were negligible at 1 mile from water. These results suggest that lighter utilization at 1 mile made the perennial grasses less susceptible to other detrimental influences than at the 1/4- or 5/8-mile distances.

Several significant three-way interactions were detected that may be used as classification devices to reveal information on relationships between species as they are influenced by the treatments. For example, the grazing-by-mesquite-by-distance interaction supports the contention that summer grazing was inferior to winter or yearlong grazing for maintaining or increasing perennial grass yields.

APPENDIX

Appendix A. Differences between blocks and years in herbage production

(in pounds per acre)

Block	1957	1958	1959	1960	1961	Sign. level (percent)
			ARIZONA COTTONTOP			
1	14.06	42.19	33.03	27.92	27.40	NS
2	5.71	16.42	14.36	7.15	12.93	
			TALL THREE-AWNS			
1	3.21	17.93	14.85	16.06	6.93	NS
2	1.51	5.65	5.75	3.29	4.53	
			ALL PERENNIAL GRASSES			
1	28.72	88.17	69.29	62.46	50.67	NS
2	19.10	67.36	53.82	30.21	43.99	
			ANNUAL GRASSES			
1	21.33	119.92	247.89	49.11	92.49	5
2	38.42	286.25	296.64	52.03	277.29	
			TOTAL GRASS			
1	50.06	208.08	317.18	111.57	145.10	1
2	57.51	353.61	350.46	82.24	321.28	

Appendix B. <u>Differences between blocks and years in utilization of perennial grasses</u>

(in percent)

Block	1957	1958	1959	1960	1961	Sign. level
			ARIZONA COTTONTOP			
1	48	55	55	60	63	NS
2	50	26	36	56	52	
			TALL THREE-AWNS			
1	10	36	37	43	36	NS
2	6	13	27	39	25	
			SANTA RITA THREE-AWN			
1	57	55	58	66	55	NS
2	52	36	49	66	50	
			BUSH MUHLY			
1	45	53	50	64	54	NS
2	47	42	36	56	49	
			ALL PERENNIAL GRASSES			
1	40	47	49	56	52	NS
2	35	21	29	51	36	

Appendix C. Differences between blocks and years in ground cover[a]

(in percent)

Block	1957	1958	1959	1960	1961	Sign. level
			INTERCEPT OF ALL PERENNIAL GRASSES			
1	0.15	0.27	0.18	0.10	0.11	NS
2	0.09	0.22	0.12	0.06	0.07	
			INTERCEPT OF BURROWEED			
1	3.23	5.58	2.36	6.61	2.81	1
2	1.47	2.11	0.80	1.72	1.59	
			INTERCEPT OF MESQUITE			
1	10.81	9.51	7.25	6.69	6.57	NS
2	3.26	3.15	2.18	1.72	2.11	
			INTERCEPT OF ALL SHRUBS			
1	17.56	19.17	12.98	16.88	11.94	1
2	9.03	10.38	7.45	7.72	7.95	

[a]Basal intercept of perennial grasses; crown intercept of shrubs

Appendix D. Differences between blocks and distances from water in herbage production

Plant class or species	Block	Distance from water: 1/4 mile	5/8 mile	1 mile	Sign. level (percent)
		- - Pounds per acre - -			
Arizona cottontop	1	20.46	30.37	35.93	1
	2	10.90	4.59	18.45	
Tall three-awns	1	7.12	8.69	19.58	1
	2	6.10	1.79	4.55	
All perennial grasses	1	42.16	62.53	74.89	NS
	2	34.34	36.76	57.58	
Annual grasses	1	109.34	122.88	87.30	NS
	2	186.85	191.53	191.99	
Total grass	1	151.58	185.42	162.19	NS
	2	221.19	228.29	249.58	

Appendix E. Differences between blocks and distances from water in utilization of perennial grasses

Plant class or species	Block	Distance from water 1/4 mile	5/8 mile	1 mile	Sign. level
		- - - - - - - Percent	- - - - - - -		
Arizona cottontop	1	58	56	55	NS
	2	47	43	42	
Tall three-awns	1	34	30	33	NS
	2	24	22	20	
Santa Rita three-awn	1	61	57	56	NS
	2	55	48	48	
Bush muhly	1	51	56	52	5
	2	52	49	36	
All perennial grasses	1	51	48	47	NS
	2	38	34	32	

Appendix F. Differences between blocks and distances from water in ground cover[a]

Plant class or species	Block	Distance from water: 1/4 mile	5/8 mile	1 mile	Sign. level
		- - - - - - - Percent - - - - - - -			
All perennial grasses	1	0.11	0.19	0.18	1
	2	0.10	0.09	0.14	
Burroweed	1	4.48	4.40	3.47	1
	2	2.03	1.32	1.26	
Mesquite	1	9.07	5.00	10.43	1
	2	1.35	2.98	3.13	
All shrubs	1	17.62	11.85	17.65	1
	2	6.52	9.49	9.52	

[a]Basal intercept of perennial grasses; crown intercept of shrubs

Appendix G. Differences between textures of subsoil and distances from water in herbage production and utilization of perennial grasses

Plant class or species	Texture of subsoil	Distance from water 1/4 mile	5/8 mile	1 mile	Sign. level (percent)
		HERBAGE PER ACRE (POUNDS)			
Arizona cottontop	Fine	19.02	23.78	30.00	NS
	Coarse	12.34	11.19	24.38	
Tall three-awns	Fine	6.27	6.32	11.02	NS
	Coarse	6.95	4.16	13.11	
All perennial grasses	Fine	46.94	61.53	65.98	NS
	Coarse	29.56	37.76	66.50	
Annual grasses	Fine	113.86	103.71	123.87	NS
	Coarse	182.33	210.71	155.43	
Total grass	Fine	160.80	165.24	189.84	NS
	Coarse	211.98	248.47	221.93	
		UTILIZATION (PERCENT)			
Arizona cottontop	Fine	53	48	46	NS
	Coarse	52	50	50	
Tall three-awns	Fine	26	22	24	NS
	Coarse	32	29	28	
Santa Rita three-awn	Fine	61	54	54	NS
	Coarse	55	53	51	
Bush muhly	Fine	47	56	38	5
	Coarse	56	50	51	
All perennial grasses	Fine	42	38	39	NS
	Coarse	47	44	40	

Appendix H. Differences between textures of subsoil and distances from water in ground cover[a]

Plant class or species	Texture of Subsoil	Distance from water 1/4 mile	5/8 mile	1 mile	Sign. level
		- - - - - Percent - - - - - -			
All perennial grasses	Fine	0.10	0.17	0.18	NS
	Coarse	0.12	0.11	0.14	
Burroweed	Fine	3.41	2.83	2.84	NS
	Coarse	3.10	2.90	1.90	
Mesquite	Fine	4.76	4.68	6.83	NS
	Coarse	5.66	3.30	6.73	
All shrubs	Fine	10.95	10.28	14.07	NS
	Coarse	13.19	11.05	13.10	

[a]Basal intercept of perennial grasses; crown intercept of shrubs

Appendix I. Differences between conditions of mesquite and distances from water in herbage production and utilization of perennial grasses

Plant class or species	Condition of mesquite	Distance from water: 1/4 mile	5/8 mile	1 mile	Sign. level (percent)
HERBAGE PER ACRE (POUNDS)					
Arizona cottontop	Killed	18.71	20.67	28.27	NS
	Alive	12.65	14.28	26.11	
Tall three-awns	Killed	9.80	7.07	15.17	NS
	Alive	3.42	3.41	8.96	
All perennial grasses	Killed	46.63	57.41	67.88	5
	Alive	29.88	41.89	64.59	
Annual grasses	Killed	175.60	178.38	173.01	NS
	Alive	120.59	136.04	106.29	
Total grass	Killed	222.31	235.78	240.89	NS
	Alive	150.47	177.92	170.87	
UTILIZATION (PERCENT)					
Arizona cottontop	Killed	51	47	45	NS
	Alive	55	52	51	
Tall three-awns	Killed	26	26	23	NS
	Alive	32	26	29	
Santa Rita three-awn	Killed	57	50	51	NS
	Alive	59	56	54	
Bush muhly	Killed	55	56	44	NS
	Alive	48	49	45	
All perennial grasses	Killed	42	38	37	NS
	Alive	47	43	42	

Appendix J. Differences between conditions of mesquite and distances from water in ground cover[a]

Plant class or species	Condition of mesquite	Distance from water: 1/4 mile	5/8 mile	1 mile	Sign. level
		- - - - - Percent - - - - - -			
All perennial grasses	Killed	0.13	0.17	0.16	NS
	Alive	0.09	0.11	0.16	
Burroweed	Killed	3.78	3.12	2.78	NS
	Alive	2.74	2.60	1.96	
Mesquite	Killed	0.94	0.62	2.39	NS
	Alive	9.49	7.36	11.17	
All shrubs	Killed	8.36	7.10	9.84	NS
	Alive	15.78	14.24	17.33	

[a]Basal intercept of perennial grasses; crown intercept of shrubs

Appendix K. Differences between textures of subsoil and conditions of mesquite in herbage production, utilization of perennial grasses, and ground cover[a]

Plant class or species	Texture of subsoil: Fine, Mesquite killed	Fine, Mesquite alive	Coarse, Mesquite killed	Coarse, Mesquite alive	Sign. level (percent)
HERBAGE PER ACRE (POUNDS)					
Arizona cottontop	30.08	18.45	16.03	16.91	1
Tall three-awns	11.53	4.21	9.83	6.32	5
All perennial grasses	70.48	45.82	44.13	45.09	1
Annual grasses	135.98	91.64	215.34	150.30	NS
Total grass	206.46	137.46	259.53	195.39	NS
UTILIZATION (PERCENT)					
Arizona cottontop	46	53	49	53	NS
Tall three-awns	22	27	28	31	NS
Santa Rita three-awn	53	59	52	54	NS
Bush muhly	48	45	55	50	NS
All perennial grasses	37	42	42	46	NS
GROUND COVER (PERCENT)					
All perennial grasses	0.17	0.13	0.14	0.11	NS
Burroweed	3.58	2.47	2.87	2.40	5
Mesquite	1.57	9.27	1.06	9.40	NS
All shrubs	8.64	14.90	8.22	16.67	5

[a]Basal intercept of perennial grasses; crown intercept of shrubs

Appendix L. Differences between distances from water and seasons of grazing in herbage production

Plant class or species	Distance from water	Season of grazing: Winter	Summer	Yearlong	Sign. level (percent)
		- - Pounds per acre - -			
Arizona cottontop	1/4 mile	12.51	6.55	27.98	
	5/8 mile	9.69	8.36	34.39	1
	1 mile	46.69	14.76	20.13	
Tall three-awns	1/4 mile	6.23	2.87	10.74	
	5/8 mile	4.39	2.84	8.50	1
	1 mile	23.79	1.90	10.50	
All perennial grasses	1/4 mile	40.11	17.38	57.26	
	5/8 mile	24.57	34.56	89.81	1
	1 mile	81.02	33.06	84.64	
Annual grasses	1/4 mile	156.45	133.38	154.47	
	5/8 mile	146.45	143.73	181.45	NS
	1 mile	103.40	151.70	163.84	
Total grass	1/4 mile	196.57	150.75	211.85	
	5/8 mile	171.01	178.29	271.26	NS
	1 mile	184.41	184.76	248.48	

Appendix M. Differences between distances from water and seasons of grazing in utilization of perennial grasses

Plant class or species	Distance from water	Season of grazing: Winter	Summer	Yearlong	Sign. level
		- - - - - - Percent - - - - - -			
Arizona cottontop	1/4 mile	56	54	48	
	5/8 mile	54	47	47	NS
	1 mile	50	45	49	
Tall three-awns	1/4 mile	41	23	23	
	5/8 mile	32	22	22	NS
	1 mile	29	19	31	
Santa Rita three-awn	1/4 mile	62	50	61	
	5/8 mile	54	48	57	NS
	1 mile	61	43	52	
Bush muhly	1/4 mile	49	49	56	
	5/8 mile	54	56	49	NS
	1 mile	51	37	45	
All perennial grasses	1/4 mile	49	42	42	
	5/8 mile	44	40	40	NS
	1 mile	45	38	36	

Appendix N. Differences between distances from water and seasons of grazing in ground cover[a]

Plant class or species	Distance from water	Season of grazing: Winter	Summer	Yearlong	Sign. level
		- - - - - Percent	- - - - - -		
All perennial grasses	1/4 mile	0.11	0.10	0.12	
	5/8 mile	0.07	0.09	0.26	5
	1 mile	0.12	0.09	0.28	
Burroweed	1/4 mile	2.75	3.22	3.81	
	5/8 mile	2.20	3.92	2.46	1
	1 mile	2.58	2.66	1.86	
Mesquite	1/4 mile	3.83	7.14	4.67	
	5/8 mile	3.27	6.29	2.40	NS
	1 mile	4.41	9.79	6.13	
All shrubs	1/4 mile	9.18	14.56	12.47	
	5/8 mile	8.16	13.34	10.50	NS
	1 mile	10.90	17.18	12.67	

[a]Basal intercept of perennial grasses; crown intercept of shrubs

Appendix O. Differences between textures of subsoil and seasons of grazing in herbage production and utilization of perennial grasses

Plant class or species	Texture of subsoil	Season of grazing: Winter	Summer	Yearlong	Sign. level (percent)
		HERBAGE PER ACRE (POUNDS)			
Arizona cottontop	Fine	21.01	9.83	41.95	1
	Coarse	24.92	7.95	13.04	
Tall three-awns	Fine	10.06	1.98	11.57	NS
	Coarse	12.88	3.09	8.26	
All perennial grasses	Fine	50.32	32.25	91.88	NS
	Coarse	46.81	24.42	62.59	
Annual grasses	Fine	83.47	115.20	142.77	NS
	Coarse	187.40	170.67	190.40	
Total grass	Fine	133.78	147.45	234.65	5
	Coarse	234.21	195.08	253.08	
		UTILIZATION (PERCENT)			
Arizona cottontop	Fine	56	46	45	1
	Coarse	50	51	51	
Tall three-awns	Fine	30	20	22	NS
	Coarse	38	23	28	
Santa Rita three-awn	Fine	62	50	54	5
	Coarse	56	44	59	
Bush muhly	Fine	46	42	53	5
	Coarse	57	53	48	
All perennial grasses	Fine	46	38	35	NS
	Coarse	47	42	43	

Appendix P. Differences between textures of subsoil and seasons of grazing in ground cover[a]

Plant class or species	Texture of subsoil	Season of grazing: Winter	Summer	Yearlong	Sign. level
		- - - - - - - Percent - - - - - - -			
All perennial grasses	Fine	0.08	0.09	0.28	1
	Coarse	0.12	0.10	0.16	
Burroweed	Fine	2.37	3.60	3.11	NS
	Coarse	2.65	2.94	2.31	
Mesquite	Fine	3.97	7.60	4.70	NS
	Coarse	3.71	7.88	4.10	
All shrubs	Fine	8.55	14.84	11.92	NS
	Coarse	10.28	15.22	11.84	

[a]Basal intercept of perennial grasses; crown intercept of shrubs

Appendix Q. Differences between conditions of mesquite and seasons of grazing in herbage production and utilization of perennial grasses

Plant class or species	Condition of mesquite	Season of grazing: Winter	Summer	Yearlong	Sign. level (percent)
		HERBAGE PER ACRE (POUNDS)			
Arizona cottontop	Killed	24.88	11.22	31.56	NS
	Alive	21.04	8.57	23.44	
Tall three-awns	Killed	15.78	3.41	12.85	1
	Alive	7.15	1.66	6.97	
All perennial grasses	Killed	55.67	29.64	86.61	5
	Alive	41.46	27.03	67.87	
Annual grasses	Killed	158.42	176.62	191.95	NS
	Alive	112.45	109.25	141.22	
Total grass	Killed	214.08	206.26	278.64	NS
	Alive	153.91	136.27	209.08	
		UTILIZATION (PERCENT)			
Arizona cottontop	Killed	51	46	46	NS
	Alive	56	51	50	
Tall three-awns	Killed	32	20	24	NS
	Alive	36	23	28	
Santa Rita three-awn	Killed	59	45	55	NS
	Alive	59	50	59	
Bush muhly	Killed	53	49	55	NS
	Alive	50	46	48	
All perennial grasses	Killed	42	38	37	NS
	Alive	49	42	42	

Appendix R. Differences between conditions of mesquite and seasons of grazing in ground cover[a]

Plant class or species	Condition of mesquite	Season of grazing: Winter	Summer	Yearlong	Sign. level
		- - - - - - - Percent - - - - - - -			
All perennial grasses	Killed	0.10	0.13	0.24	NS
	Alive	0.10	0.06	0.20	
Burroweed	Killed	2.75	3.76	3.17	NS
	Alive	2.27	2.77	2.26	
Mesquite	Killed	1.38	1.54	1.02	1
	Alive	6.30	13.94	7.78	
All shrubs	Killed	7.13	9.58	8.58	1
	Alive	11.70	20.47	15.18	

[a]Basal intercept of perennial grasses; crown intercept of shrubs

LITERATURE CITED

Albertson, F. W., Andrew Riegel, and John L. Launchbaugh, 1953. Effects of different intensities of clipping on short grasses in west-central Kansas. Ecology 34(1): 1-20.

______, G. W. Tomanek, and Andrew Riegel, 1957. Ecology of drought cycles and grazing intensity on grasslands of central Great Plains. Ecological Mono. 27(1): 27-44.

Anderson, E. William, 1956. Some soil-plant relationships in eastern Oregon. Jour. Range. Mangt. 9(4):171-175.

Anderson, Kling L. and Claude L. Fly, 1955. Vegetation-soil relationships in Flint Hills bluestem pastures. Jour. Range Mangt. 8(4):163-169.

Beetle, A. A., W. M. Johnson, R. L. Lang, Morton May, and D. R. Smith, 1961. Effect of grazing intensity on cattle weights and vegetation of the Bighorn experimental pastures. Univ. of Wyoming, Agr. Expt. Sta. Bull. 373, 23 p.

Blaisdell, James P. and Joseph F. Pechanec, 1949. Effects of herbage removal at various dates on vigor of bluebunch wheatgrass and arrowleaf balsamroot. Ecology 30(3): 298-305.

Bowns, James E. Jr. and Thadis W. Box, 1964. The influence of grazing on the roots and rhizomes of seacoast bluestem. Jour. Range Mangt. 17(1):36-39.

Branscomb, Bruce L., 1958. Shrub invasion of a southern New Mexico desert grassland range. Jour. Range Mangt. 11(3):129-132.

Branson, Farrel A., 1953. Two new factors affecting resistance of grasses to grazing. Jour. Range Mangt. 6(3): 165-171.

______, 1956. Quantitative effects of clipping treatments on five range grasses. Jour. Range Mangt. 9(2):86-88.

Brown, Albert L., 1950. Shrub invasion of southern Arizona desert grassland. Jour. Range Mangt. 3(3): 172-177.

Campbell, R. S., 1929. Vegetative succession in the *Prosopis* sand dunes of southern New Mexico. Ecology 10(4):392-398.

______, 1931. Plant succession and grazing capacity on clay soils in southern New Mexico. Jour. Agr. Res. 43(12): 1027-1051.

Canfield, R. H., 1939. The effect of intensity and frequency of clipping on density and yield of black grama and tobosa grass. U.S. Dept. Agr. Tech. Bull. 681, 32 p.

______, 1941. Application of the line interception method in sampling range vegetation. Jour, Forestry 39:388-394.

______, 1948. Perennial grass composition as an indicator of condition of southwestern mixed grass ranges. Ecology 29(2):190-204.

Clarke, S. E., E. W. Tisdale, and N. A. Skoglund, 1943. The effects of climate and grazing practices on short-grass prairie vegetation in southern Alberta and southwestern Saskatchewan. Canadian Dept. Agr. Publ. 747, Tech. Bull. 46, 53 p.

Clements, F. E., F. L. Long, and E. V. Martin, 1940. Ecology -- Adaptation and origin. Carnegie Inst. of Washington Yearbook 39, 167-175.

Cochran, William G. and Gertrude M. Cox, 1957. Experimental Designs, 2nd Edition. John Wiley & Sons, Inc., New York. 611 pp.

Cook, C. Wayne, L. A. Stoddart, andLorin E. Harris, 1953. Effects of grazing intensity upon the nutritive value of range forage. Jour. Range Mangt. 6(1):51-54.

______, L. A. Stoddart, and Floyd E. Kinsinger, 1958. Responses of crested wheatgrass to various clipping treatments. Ecological Mono. 28(3):237-272.

______, and L. A. Stoddart, 1963. The effect of intensity and season of use on the vigor of desert range plants. Jour. Range Mangt. 16(6):315-317.

Crider, Franklin J., 1955. Root-growth stoppage resulting from defoliation of grass. U.S. Dept. Agr. Tech. Bull. 1102, 23 p.

Culley, Matt, 1937. How to get sustained forage production in grazing semi-desert mixed grass ranges. Western Livestock Jour., April 27.

______, 1941. Does it rain less now than in the old days? Western Livestock Jour., July 15.

______, 1943. Grass grows in summer or not at all. The American Hereford Jour., September 1.

Darrow, Robert A., 1944. Arizona range resources and their utilization: I. Cochise County. Univ. of Ariz. Tech. Bull. 103, 311-366.

Dillon, Claude C., 1958. Benefits of rotation-deferred grazing on northwest ranges. Jour. Range Mangt. 11(6): 278-281.

Duncan, David B., 1955. Multiple range and multiple F tests. Biometrics 11(1):1-42.

Ellison, Lincoln, 1956. Grazing standards in range management. New Zealand Grassland Assn. Proc. of the 18th Conference, Canterbury Agr. College, Lincoln, November 27-29.

______, 1959. Role of plant succession in range management. Grasslands, Amer. Assn. for the Advancement of Sci., 307-321.

______, 1960. Influence of grazing on plant succession of rangelands. Bot. Rev. 26(1):1-78.

Fisher, C. E., C. H. Meadors, R. Behrens, E. D. Robinson, P. T. Marion, and H. L. Morton, 1959. Control of mesquite on grazing lands. Texas Agr. Exp. Sta. Bull. 935. 24 p.

Frandsen, Waldo R., 1950. Management of reseeded ranges. Jour. Range Mangt. 3(2):125-129.

Glendening, George E., 1944. Some factors affecting cattle use of northern Arizona pine-bunchgrass ranges. U.S. Dept. Agr., Forest Service, Southwestern Forest and Range Exp. Sta. Rpt. 6, 9 p.

______, and Harold A. Paulsen, Jr., 1955. Reproduction and establishment of velvet mesquite as related to invasion of semidesert grasslands. U.S. Dept. Agr. Tech. Bull. 1127, 50 p.

Griffiths, David, 1901. Range improvement in Arizona. U.S. Dept. Agr. Bur. Plant Ind. Bull. 4, 31 p.

______, 1904. Range investigations in Arizona. U.S. Dept. Agr. Bur. Plant Ind. Bull. 67, 62 p.

______, 1910. A protected stock range in Arizona. U.S. Dept. Agr. Bur. Plant Ind. Bull. 177, 28 p.

Haskell, Horace S., 1945. Successional trends on a conservatively grazed desert grassland range. Jour. Amer. Soc. Agron. 37(12):978-990.

Heady, Harold F., 1961. Continuous vs. specialized grazing systems: A review and application to the California annual type. Jour. Range Mangt. 14(4):182-193.

______, 1964. Palatability of herbage and animal preference. Jour. Range Mangt. 17(2):76-82.

Hedrick, Donald W., 1958. Proper utilization -- A problem in evaluating the physiological response of plants to grazing use: A review. Jour. Range Mangt. 11(1):34-43.

Herbel, Carlton H. and Kling L. Anderson, 1959. Response of true prairie vegetation on major Flint Hills range sites to grazing treatment. Ecological Mono. 29(2):171-186.

Hormay, A. L., 1961. Rest-rotation grazing ... A new management system for perennial bunchgrass ranges. U.S. Dept. Agr., Forest Service Production Res. Rpt. 51, 43 p.

Hubbard, William A., 1951. Rotational grazing studies in western Canada. Jour. Range Mangt. 4(1):25-29.

Humphrey, R. R., 1953. The desert grassland, past and present. Jour. Range Mangt. 6(3):159-164.

______, 1958. The desert grassland -- A history of vegetational change and an analysis of causes. Bot. Rev. 24(4):193-252.

______, and L. A. Mehrhoff, 1958. Vegetation changes on a southern Arizona grassland range. Ecology 39(4):720-726.

Hyder, Donald N. and W. A. Sawyer, 1951. Rotation-deferred grazing as compared to season-long grazing on sagebrush-bunchgrass ranges in Oregon. Jour. Range Mangt. 4(1): 30-34.

Jameson, Donald A., 1963. Responses of individual plants to harvesting. Bot. Rev. 29(4):532-594.

______, and Donald L. Huss, 1959. The effect of clipping leaves and stems on number of tillers, herbage weights, root weights, and food reserves of little bluestem. Jour. Range Mangt. 12(3):122-126.

Johnson, W. M., 1953. Effect of grazing intensity upon vegetation and cattle gains on ponderosa pine-bunchgrass ranges of the Front Range of Colorado. U.S. Dept. Agr. Cir. 929, 36 p.

______, 1956. The effect of grazing intensity on plant composition, vigor, and growth of pine-bunchgrass ranges in central Colorado. Ecology 37(4):790-798.

______, 1959. Grazing intensity trials on seeded ranges in the ponderosa pine zone of Colorado. Jour. Range Mangt. 12(1):1-7.

Kearney, Thomas H. and Robert H. Peebles, 1951. Arizona Flora. University of California Press, Berkeley and Los Angeles. 1032 p.

Kincaid, D. R., G. A. Holt, P. D. Dalton, and J. S. Tixier, 1959. The spread of Lehmann lovegrass as affected by mesquite and native perennial grasses. Ecology 40(4): 738-742.

Klipple, G. E. and R. E. Bement, 1961. Light grazing -- is it economically feasible as a range-improvement practice. Jour. Range Mangt. 14(2):57-62.

______ and David F. Costello, 1960. Vegetation and cattle responses to different intensities of grazing on shortgrass ranges on the central Great Plains. U.S. Dept. Agr. Tech. Bull. 1216, 82 p.

Larin, I. V., 1960. Pasture Rotation. (Translated from Russian) Jerusalem, Israel Program for Sci. Translations, 1962, 204 p.

Laude, Horton M., Amram Kadish and R. Merton Love, 1957. Differential effect of herbage removal on range species. Jour. Range Mangt. 10(3):116-120.

Lister, Paul B. and Francis X. Schumacher, 1937. The influence of rainfall upon tuft area and height growth of three semidesert range grasses in southern Arizona. Jour. Agr. Res. 54(2):109-121.

McCarty, Edward C. and Raymond Price, 1942. Growth and carbohydrate content of important mountain forage plants in central Utah as affected by clipping and grazing. U.S. Dept. Agr. Tech. Bull. 818, 51 p.

Merrill, Leo B., 1954. A variation of deferred rotation grazing for use under southwest range conditions. Jour. Range Mangt. 7(4):152-154.

Mueggler, Walter F., 1950. Effects of spring and fall grazing by sheep on vegetation of the Upper Snake River plains. Jour. Range Mangt. 3(4):308-315.

Neiland, Bonita Miller and John T. Curtis, 1956. Differential responses to clipping of six prairie grasses in Wisconsin. Ecology 37(2):355-365.

Nelson, Enoch W., 1934. The influence of precipitation and grazing upon black grama grass range. U.S. Dept. Agr. Tech. Bull. 409, 32 p.

Nichol, A. A., 1937. The natural vegetation of Arizona. Univ. of Ariz. Tech. Bull. 68, 181-222.

Parker, Kenneth W., 1949. Control of noxious range plants in a range management program. Jour. Range Mangt. 2(3): 128-132.

______ and S. Clark Martin, 1952. The mesquite problem on southern Arizona ranges. U.S. Dept. Agr. Cir. 908, 70 p.

______ and W. G. McGinnies, 1941. Mesquite -- The silent invader. The Cattleman, May.

______ and Arthur W. Sampson, 1931. Growth and yield of certain gramineae as influenced by reduction of photosynthetic tissue. Hilgardia 5(10):362-381.

Paulsen, Harold A. Jr., 1953. A comparison of surface soil properties under mesquite and perennial grass. Ecology 34(4):727-732.

______ and Fred N. Ares, 1961. Trends in carrying capacity and vegetation on an arid southwestern range. Jour. Range Mangt. 14(2):78-83.

______ and Fred N. Ares, 1962. Grazing values and management of black grama and tobosa grasslands and associated shrub ranges of the Southwest. U.S. Dept. Agr. Tech. Bull. 1270, 56 p.

Passey, H. B. and V. K. Hugie, 1962. Application of soil-climate-vegetation relations to soil survey interpretations for rangelands. Jour. Range Mangt. 15(3):162-166.

Pechanec, Joseph F., 1949. Grazing spring-fall sheep ranges of southern Idaho. U.S. Dept. Agr. Cir. 808, 34 p.

Pond, Floyd W., 1960. Vigor of Idaho fescue in relation to different grazing intensities. Jour. Range Mangt. 13(1):28-30.

______, 1961. Effect of three intensities of clipping on the density and production of meadow vegetation. Jour. Range Mangt. 14(1):34-38.

Reed, Merton J. and Roald A. Peterson, 1961. Vegetation, soil, and cattle responses to grazing on northern Great Plains range. U.S. Dept. Agr. Tech. Bull. 1252, 79 p.

Reynolds, Hudson G., 1954. Meeting drought on southern Arizona rangelands. Jour. Range Mangt. 7(1):33-40.

______, 1959. Managing grass-shrub cattle ranges in the southwest. U.S. Dept. Agr. Handbook 162, 40 p.

Roach, M. E., 1950. Estimating perennial grass utilization on semidesert cattle ranges by percentage of ungrazed plants. Jour. Range Mangt. 3(3): 182-185.

Robocker, W. C., 1958. Some characteristics of soils and associated vegetation infested with halogeton. Jour, Range Mangt. 11(5):215-220.

Rogler, George A., 1951. A twenty-five year comparison of continuous and rotation grazing in the northern plains. Jour. Range Mangt. 4(1):35-41.

Ruby, Ellis S. and Vernon A. Young, 1953. The influence of intensity and frequency of clipping on the root system of brownseed paspalum. Jour. Range Mangt. 6(2):94-99.

Sampson, Arthur W., 1919. Plant succession in relation to range management. U.S. Dept. Agr. Bull. 791, 76 p.

______, 1951. A symposium on rotation grazing in North America. Jour. Range Mangt. 4(1):19-24.

Schultz, E. F. Jr., 1955. Rules of thumb for determining expectations of mean squares in analysis of variance. Biometrics 2(2):123-135.

Schuster, Joseph L., 1964. Root development of native plants under three grazing intensities. Ecology 45(1):63-70.

Shantz, H. L. and Raphael Zon, 1924. The natural vegetation of the United States. In Atlas of American Agriculture, Part I, Section E (Advance Sheets 6). U.S. Government Printing Office, 1936. 29 p.

Shreve, Forrest, 1931. Physical conditions in sun and shade. Ecology 12(1):96-104.

Smith, Edwin L., 1960. Effects of burning and clipping at various times during the wet season on tropical tall grass range in northern Australia. Jour. Range Mangt. 13(4):197-203.

Smoliak, S., 1960. Effects of deferred-rotation and continuous grazing on yearling steer gains and shortgrass prairie vegetation of southeastern Alberta. Jour. Range Mangt. 13(5):239-243.

Stoddart, L. A., 1946. Some physical and chemical responses of *Agropyron spicatum* to herbage removal at various seasons. Utah Agr. Expt. Sta. Bull. 324, 24 p.

Streets, R. B. and E. B. Stanley, 1938. Control of mesquite and noxious shrubs on southern Arizona grassland ranges. Univ. of Ariz. Tech. Bull. 74, 469-497.

Thornber, J. J., 1910. The grazing ranges of Arizona. Ariz. Agr. Expt. Sta. Bull. 65, 245-360.

Upson, Arthur and W. J. Cribbs, 1937. Occurrence of shrubs on range areas in southeastern Arizona. U.S. Dept. Agr., Forest Service Mimeo.Rpt., 30 p.

U.S. Forest Service, 1960. Annual Report, Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo. 59-61.

Weaver, J. E., 1950. Effects of different intensities of grazing on depth and quantity of roots of grasses. Jour. Range Mangt. 3(2):100-113.

______ and F. W. Albertson, 1940. Deterioration of midwestern ranges. Ecology 21(2):216-236.

______ and Frederick E. Clements, 1929. Plant ecology. McGraw-Hill Book Company, Inc., New York, 520 p.

______ and V. H. Hougen, 1939. Effect of frquent clipping on plant production in prairie and pasture. Amer. Midland Naturalist 21(2):396-414.

Wilm, H. G., 1945. Notes on analysis of experiments replicated in time. Biometrics 1(2):16-20.

______, David F. Costello, and G. E. Klipple, 1944. Estimating forage yield by the double-sampling method. Jour. Amer. Soc. Agron. 36:194-203.

White, E. M., 1961. A possible relationship of little bluestem distribution to soils. Jour. Range Mangt. 14(5):243-247.

Wooton, E. O., 1916. Carrying capacity of grazing ranges in southern Arizona. U.S. Dept. Agr. Bull. 367, 40 p.

Youngs, F.O., A. T. Sweet, A. T. Strahorn, T. W. Glassey, and E. N. Poulson, 1936. Soil survey of the Tucson area, Arizona. U.S. Dept. Agr. Publ. 19, Series 1931, 60 p.