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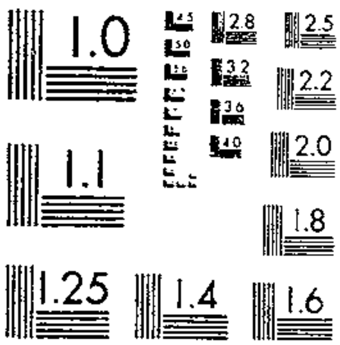

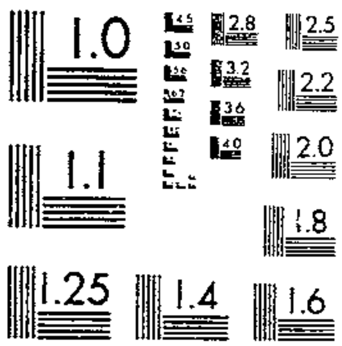

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Ecological Responses of Native Plants and Guidelines for Management of Shortgrass Range

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CONTENTS

Ecological Responses of Native Plants and Guidelines for Management of Shortgrass Range

D. N. HYDER, R. E. BEMENT,[1] E. E. REMMENGA, and D. F. HERVEY, *range scientists, Agricultural Research Service; and Professor of Statistics and Professor of Range Science, deceased, Colorado State University, respectively, Fort Collins, Colo.*

INTRODUCTION

The purpose of the study was to determine (a) the treatment and weather conditions that change the frequencies of plant species on shortgrass plains and (b) the effects on a single range site of repeated heavy grazing in individual months. The impetus for the study arose from the fact that no significant changes in the occurrence of plant species were found after 23 years of light, moderate, and heavy season-long (May 1 to November 1) grazing at the Central Plains Experimental Range (*23*).[2] Rather, the major effect of heavy grazing was a reduction in herbage yield (*29*).

The basic premise of the study was that heavy grazing for a short period of time, especially when repeated for several years, might reveal new facts about the susceptibility or resistance of native plant species to excessive defoliation by cattle. Because nitrogen (N) fertilization might affect both plant and animal responses, low-level rates of N were superimposed on grazing treatments in a factorial design that permitted isolation of the effects of time of grazing, N, treatment interactions, and weather conditions. A major goal of the study was to determine whether certain combinations of treatments could be used to manipulate the frequencies of species for improvement in range condition.

Measurements or estimations of herbage yield and herbage cover are most common in range research, but these parameters are highly ephemeral for herbaceous plant species. At best, they provide statistically reliable data for only a very few species.

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[1] Retired.

[2] Italic numbers in parentheses refer to Literature Cited, p. 84.

Plant density (the number of individuals per unit area) and frequency of occurrence are far more stable and definitive than herbage yield and cover for herbaceous species. However, density imposes problems in both objectivity and speed of sampling. Frequency of occurrence appears to be the only parameter that can be sampled with sufficient objectivity and speed to encompass enough landscape for statistically reliable data about all common herbaceous species. Unfortunately, much of the older literature included frequency data that were inadequate either in terms of quadrat size or in the number of quadrat placements per observation. Those deficiencies invited distrust and disdain for frequency of occurrence, but did not stop improper applications of the method. Satisfactory techniques for frequency sampling have been developed and defined in recent years (*20, 22, 43*). The techniques developed for shortgrass plains were used in this study. Consequently, the study has a secondary objective of further evaluating the usefulness of frequency data.

Heavy grazing at certain times might cause rapid and predictable plant responses; whereas, light or deferred grazing should leave the vegetation free to respond to weather conditions. Thus, repeated heavy grazing in short seasons is presented as a treatment that needs to be understood and applied with as much confidence as one applies chemical or mechanical treatments. For example, Laycock (*30*) reported that heavy fall grazing improved sagebrush-bunchgrass range in Idaho, and the practice of heavy fall grazing was better than protection.

The duration of this experiment can be criticized as insufficient to show all accumulative effects of the treatments. Because moderate continuous grazing, as defined by Bement (*3*), constitutes standard management practice on shortgrass plains, longtime accumulative effects of heavy grazing in short seasons would offer only academic interest. Our main concern regarding the length of this experiment is that treatment effects vary with weather conditions. We have not yet seen all possible interactions of weather and treatment. Nevertheless, the occurrence of record low and high precipitation amounts in the 7 years gives a wider range of vegetational responses than could be expected in longer periods of time.

Heavy grazing by individual months has not been previously evaluated. The results obtained hopefully may lead to better methods of manipulating vegetation for range improvement and to a philosophical acceptance of short-duration heavy grazing as potentially desirable and beneficial to rangelands.

METHODS

This was a 12-season by two-fertility-rate factorial experiment in two replications that included forty-eight 3.5-acre pastures (fig. 1). The seasons of repeated heavy grazing were individual

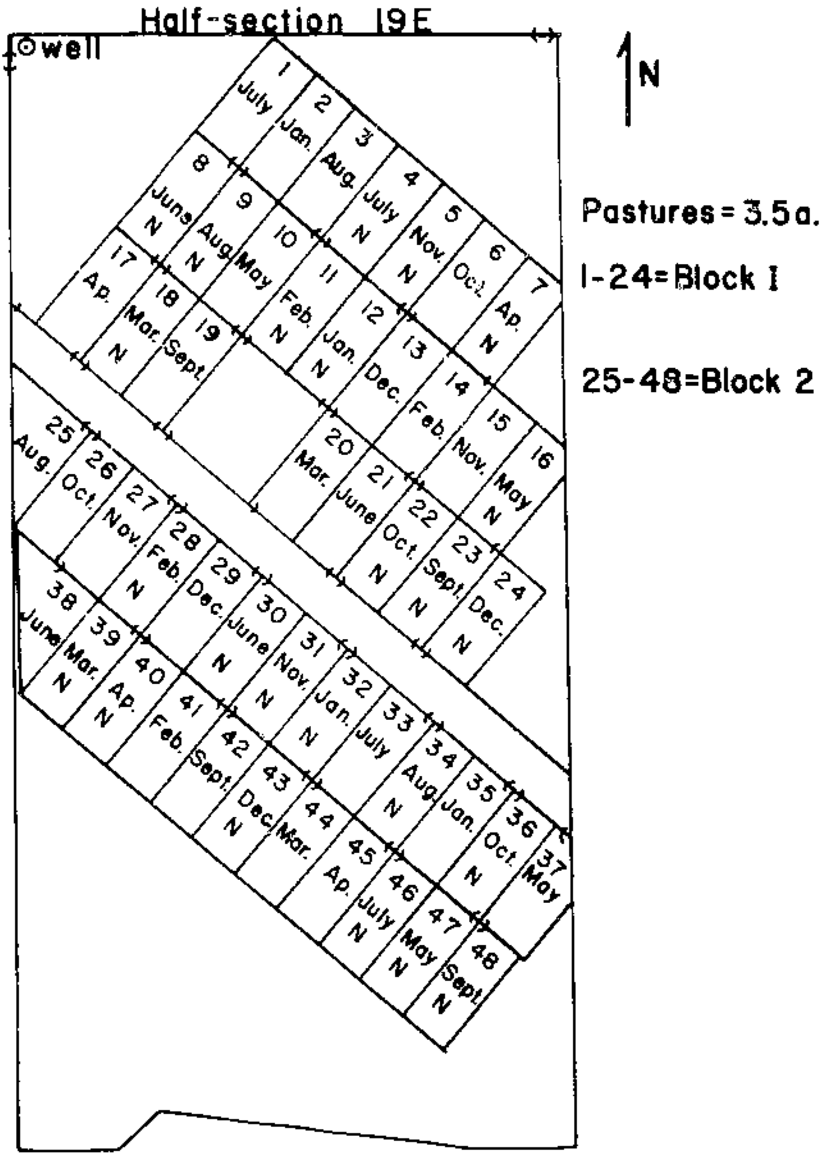

FIGURE 1.—Pasture arrangement for repeated heavy grazing and N fertilization.

calendar months, and the fertility rates were 0 and 20 pounds N per acre annually. Ammonium nitrate was broadcast annually with a fluted-feed grain drill in October of each year 1963–69, inclusive.

The experimental pastures, 38 miles northeast of Fort Collins, Colo., on the Central Plains Experimental Range, were stocked at the first of a month with the estimated number of yearling Hereford heifers needed to utilize all but 100 lb/acre (dry weight basis) of herbage in 4 weeks. Grazing continued until utilization was complete rather than for a certain number of days. This degree of utilization was very heavy (fig. 2) and would have been harmful to cattle if continued for several months. Therefore, the heifers were rotated monthly from experimental pastures to a half-section holding pasture to prevent the accumulation of heavy-grazing effects in animal gains.

All animals were weighed individually in and out of the experimental pastures following an overnight shrink in dry lot (fig. 3). Yearling heifers were received from local ranchers in April each year and were retained 12 months. Grazing began in May 1963, but the first year was reserved for establishing the months of grazing. Therefore, the cattle were not weighed to and from the experimental pastures until May 1964. In 1963, nearly all

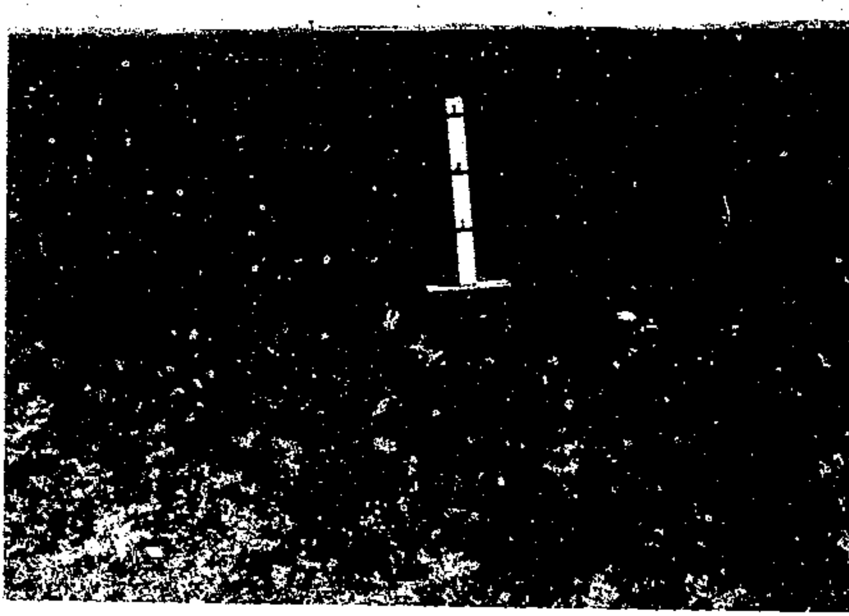

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FIGURE 2.—Appearance of vegetation after very heavy grazing.

herbage growth occurred in August. In 1964, herbage did not grow enough to appear green at any time, and herbage production was less than 100 lb/acre. Consequently, grazing was suspended from August 1, 1964, until August 1, 1965. The year of initial grazing by individual months and the year of nonuse reduced the data base for animal responses to 5 of the 7 years.

Animal data were used as indications of the quantity and quality of forage harvested under repeated heavy grazing by individual months. The animal days of grazing per acre were adjusted to compensate for trends in liveweight. This adjustment was based on animal metabolic size, calculated as liveweight to the 0.75 power ($W^{0.75}$). The adjusted values are called animal-unit

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FIGURE 3.—*A*, Livestock weighing facilities and, *B*, moving livestock to drylot pens.

days of grazing because the standard counted as 1 animal-unit day of grazing was the metabolic size of an animal weighing 1,200 pounds. The yearlings never weighed as much; therefore, the proportional animal-unit day attributed to smaller animals was as follows:

Pounds of liveweight	*Proportion of an animal-unit day*
400	0.44
500	.52
600	.59
700	.67
800	.74
900	.80
1,000	.87
1,100	.94
1,200	1.00

Animal liveweights were used to compute animal daily gains and liveweight gains per acre. Liveweights and gains were used to estimate the amounts of net energy harvested and utilized in maintenance and gain according to the requirements recommended by the National Research Council (*32*).

Pastures in Block 1 (see fig. 1) were located on Manter sandy loam, and those in Block 2 were on Vona fine sandy loam. These soils were tentatively identified as McGrew sandy loam and Greeley sandy loam, respectively, in a 1960 soil survey by the Soil Conservation Service, U.S. Department of Agriculture, and were later revised. The Manter series is a member of the coarse-loamy, mixed, mesic family of Aridic Argiustolls. They typically have very friable granular noncalcareous *A* horizons, moderately coarse-textured noncalcareous *B2+* horizons of prismatic and blocky structure, and moderately coarse-textured, calcareous *C* horizons with continuous subhorizons of secondary calcium carbonate accumulation. The Vona series is a member of the coarse-loamy, mixed, mesic family of Ustollic Haplargids. Typically, they have very friable granular *A* horizons, moderately coarse-textured *B2+* horizons, and weak to moderate horizons of secondary calcium carbonate accumulation. These soils, being very similar in texture, permeability, and depth, are included in the Sandy Plains Range Site (fig. 4).

Vegetation analyses were based on the frequency of occurrence of individual species as observed in the last 2 weeks of June each year, 1963 through 1970. Two permanent macroplots, measuring 75 by 100 feet, were located in each pasture. Each macroplot was evaluated with 250 quadrat placements allocated 25 in each

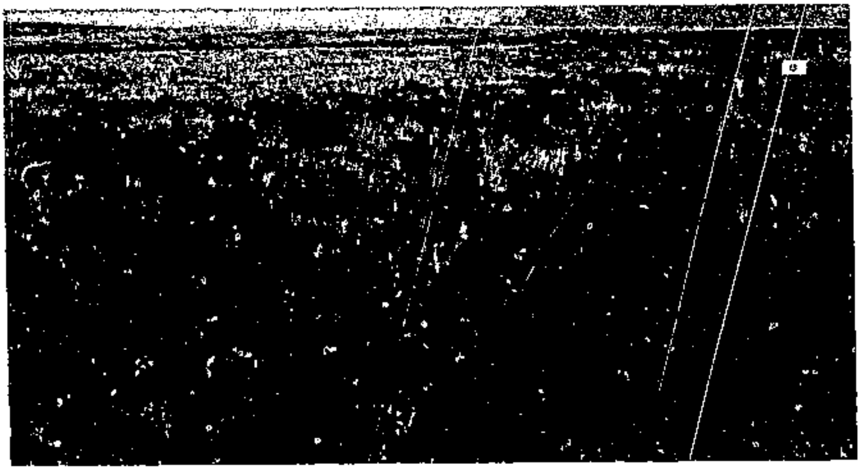

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FIGURE 4.—The Sandy Plains Range Site on shortgrass plains of Colorado.

of 10 transects, which were located at restricted-random positions each year. Quadrats were placed systematically at 3-foot intervals along the transect, and the frequency percentages of individual species were recorded at the end of each transect. The annual sample included 24,000 quadrat placements with 500 placements in each of the 48 pastures.

The sampling frame included a pair of quadrats mounted on a handle (*22*). A large 16- by 16-inch quadrat included a small 2- by 2-inch quadrat in one corner. Blue grama was sampled with the 2-inch quadrat and all other species with the 16-inch quadrat. At each quadrat placement, an observer named the species present while an assistant accumulated the observations by dropping beads in a set of labeled tubes (fig. 5). Plant species were identified according to Harrington (*13*).

Frequency data obtained in 1964 to 1970 were analyzed by covariance on frequency percentages prevailing in 1963 to determine treatment effects. The covariance permits the calculation of adjusted frequency percentages as though a species appeared in every sample at the overall mean frequency percentage in the base year, 1963. In any subsequent year, differences among adjusted mean frequency percentages are interpreted, when significant, by Duncan's smallest significant range (SSR) calculated at 5 percent for the number of means being compared. Frequency percentages at or above the upper limit of the SSR designate increaser-type responses, and those at or below the lower limit of the SSR designate decreaser-type responses. The SSR is shown in graphs as a vertical bracket.

PN-3865

FIGURE 5.—Tally equipment for frequency of occurrence of individual plant species.

Changes in frequency among years were tested for significance by the confidence interval for binomial distributions at the 5-percent level of probability. With 24,000 quadrat placements each year, a change in frequency percentage of 1 percent was significant.

Differences or changes in frequency percentage are numerically smaller than would be the case with plant-density data. In effect, frequency data provide nonlinear comparisons among samples. For some species, especially forbs, linear comparisons can be obtained by calculating plant density (number of plants per quadrat) from the frequency percentage (*12*). This transformation from frequency to density is often very helpful, because the direct determination of plant density can be difficult and time consuming. Frequency requires a simple tally of the species present. Therefore, sampling moves along quickly and permits the observation of a large total area of land. When individual samples are large, say over 200 quadrat placements, differences among samples may be interpreted by either binomial or normal theory statistics.

The mean annual precipitation is 12.3 inches. In the years 1963–70, inclusive, precipitation varied from a low of 4.3 inches in 1964 to a high of 22.9 inches in 1967 (fig. 6). These amounts were the smallest and largest ever recorded at the Central Plains Experimental Range in 31 years. Although there was severe drought in 1964, this period of 7 years included 5 years with above-average precipitation. The sequence of wet years, and wide extremes in precipitation in 1964 and 1967, contributed to a large number of plant responses.

Air temperature deviations from the mean have been mostly negative in the last 7 years (table 1), but it is difficult to establish the role of temperature in plant dynamics when precipitation is so deficient (*10*).

Because the amounts and seasonal distributions of precipitation may determine plant responses, the dependence of species on quarterly precipitation amounts received in the 2 years before the time of frequency sampling in June each year was calculated by multiple stepwise regression. The independent variable P_1 included the amount of precipitation received in the spring (March, April, and May) before sampling in June. Independent variable P_2 included precipitation in the preceding winter quarter of December, January, and February. The other independent variables, up to P_8, go backward in time by 3-month intervals (table 2). For quick recognition in the text, these eight independent variables

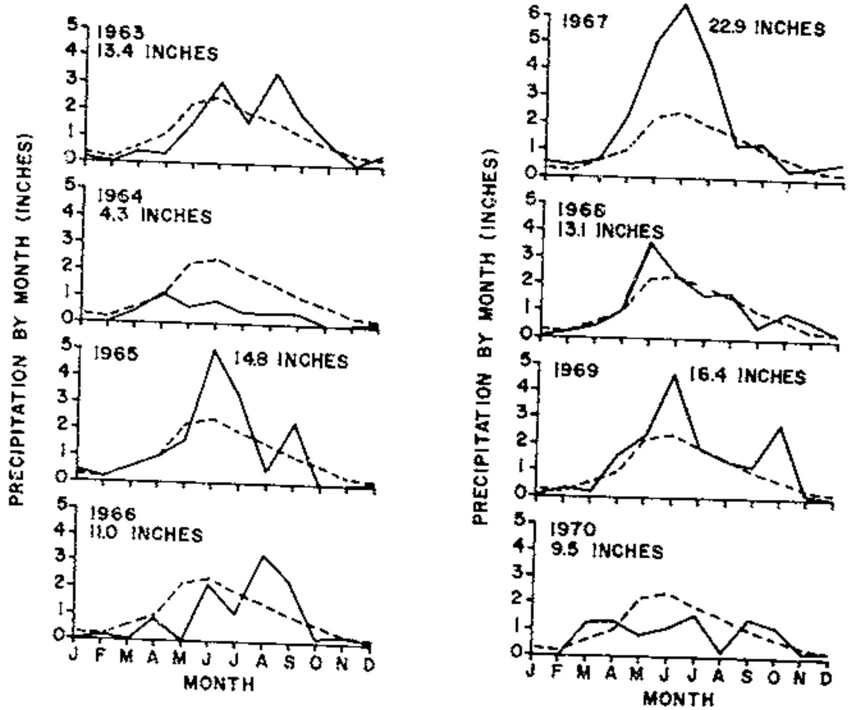

FIGURE 6.—Monthly and annual precipitation amounts at the Central Plains Experimental Range in 1963 through 1970. The 30-year mean is plotted as a broken line for evaluating precipitation in individual years.

TABLE 1.—*Twenty-year mean monthly temperatures, in degrees Fahrenheit, and deviations from the mean in 1963–69*

Month	Deviations from mean							20-year mean
	1963	1964	1965	1966	1967	1968	1969	
January	− 6	+ 3	+ 8	0	+ 4	+ 4	+ 4	24
February	+ 1	− 6	− 5	− 7	− 2	0	0	31
March	0	− 8	− 4	+ 4	+ 2	+ 1	− 8	34
April	+ 1	− 2	− 3	− 4	+ 1	− 3	+ 3	43
May	+ 2	+12	− 2	− 2	− 4	− 6	+ 1	54
June	− 1	− 3	− 5	− 1	− 7	0	− 8	63
July	+ 3	+ 3	− 2	+ 5	− 3	− 2	− 2	69
August	+ 1	− 3	− 2	− 2	0	− 5	+ 3	67
September	+ 2	− 2	−10	− 2	− 4	− 3	+ 2	60
October	+ 8	− 2	+ 3	− 5	− 2	− 2	−12	50
November	+ 2	− 3	− 1	0	+ 2	− 2	+ 1	36
December	− 6	− 2	+ 1	− 4	− 7	− 5	−12	30
Sum	+ 7	−13	−22	−18	−20	−23	−28	

are symbolized *SP*–1, *W*–1, *F*–1, *S*–1, and so forth, as shown in table 2.

The main deficiency in the multiple stepwise regression is the limitation imposed by 8 years of data. As a consequence, the multiple correlation coefficient (R) approaches 1.0 at step 7. The regression equations were limited to a maximum of four steps, the best four of the quarterly precipitation amounts, and stopped at fewer than four steps when R was significant. Even so, the reliability of the regresson equations should be evaluated in terms of the standard error of estimate (SEE), which is given with each equation.

The regression equations were derived from 8 years of data, 1963 through 1970, and were tested for predictability value by comparing calculated frequency percentages ($\hat{Y}$) with true frequency percentages obtained in 1971 and 1972.

Plant community relations were considered in several ways, but the most valuable analyses were also the least complicated. Simple linear correlation coefficients between pairs of species identified the significant positive and negative relations. The species were sorted into sets that included most of the positive correlations leaving negative correlations between sets. This grouping of species by sets in the correlation matrix provided a general view of association among the 27 most frequent species. Among those 27 species, the apparent dependence of any single species on all the remainder was determined by multiple stepwise regression to test the hypothesis that infrequent species are dependent on a few "key" species. If this hypothesis were correct, the key species could be identified as independent variables and used to predict the frequency percentages of other species.

RESULTS

Sources of Significant Changes in Plant Frequencies

In one or more samples, 53 species (table 3) attained frequencies of 5 percent or more. All of these species were included in data analyses. The 27 most common species (15 perennials and 12 annuals) responded significantly to year and treatment effects (table 4). The list of significant effects included 226 plant responses to be accounted for. Fifty-four percent of them were due to year effects; 26 percent, to N fertilization; 16 percent, to months of repeated heavy grazing; and 4 percent, to treatment interaction. Perennial species accounted for 38 percent of the significant effects as compared with 62 percent for annual species.

TABLE 2.—*Quarterly precipitation amounts, in inches, received in the 2 years before the time of frequency sampling in June each year, 1963–72*

Year of sampling	Quarterly periods before the time of sampling:[1]							
	Spring P_1 *SP–1*[2]	Winter P_2 *W–1*	Fall P_3 *F–1*	Summer P_4 *S–1*	Spring P_5 *SP–2*	Winter P_6 *W–2*	Fall P_7 *F–2*	Summer P_8 *S–2*
1963	2.30	0.35	2.07	9.22	3.21	1.34	3.20	7.04
1964	2.10	.43	2.60	7.91	2.30	.35	2.07	9.22
1965	3.14	.72	.40	1.60	2.10	.43	2.60	7.91
1966	1.01	.34	2.34	8.66	3.14	.72	.40	1.60
1967	7.74	.94	3.00	6.72	1.01	.34	2.34	8.66
1968	5.05	.78	1.92	11.82	7.74	.94	3.00	6.72
1969	4.07	.38	2.04	5.59	5.05	.78	1.92	11.82
1970	3.49	.10	4.14	7.78	4.07	.38	2.04	5.59
1971	5.38	.98	2.78	2.94	3.49	.10	4.14	7.78
1972	5.08	.78	2.31	2.20	5.38	.98	2.78	2.94
30-year mean	3.77	.66	1.96	5.83	--	--	--	--

[1] The spring period of variable P_1 includes March, April, and May immediately before a sampling date, and subsequent variables include earlier quarters in reverse chronological order. The precipitation amounts relative to sampling in the years 1963–70 entered stepwise regression as independent variables, and those relative to 1971 and 1972 were used to test the predictive value of regression equations.

[2] For clarity in the text, the 8 independent variables of quarterly precipitation amounts are symbolized to designate seasons.

TABLE 3.—*Most common plant species on the Sandy Plains Range Site*

Symbol[1]	Scientific name and author	Common name
AGSM	*Agropyron smithii* Rydb.	Western wheatgrass.
AGTR	*A. trachycaulum* (Link) Malte	Slender wheatgrass.
ALTE	*Allium textile* (A. Nels. & Macbr.)	Textile onion.
ARFR4	*Artemisia frigida* Willd.	Fringed sagewort.
ARLO3	*Aristida longiseta* Steud.	Red threeawn.
ASGR3	*Astragalus gracilis* Nutt.	Littleleaf milkvetch.
ASTRA	*Astragalus* L.	Milkvetch.
BAOP	*Bahia oppositifolia* (Nutt.) DC.	Plains bahia.
BOGR2	*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.	Blue grama.
BUDA	*Buchloe dactyloides* (Nutt.) Engelm.	Buffalograss.
CAFI	*Carex filifolia* Nutt.	Threadleaf sedge.
CAHE5	*C. heliophila* Mackenz.	Sun sedge.
CHAL7	*Chenopodium album* L.	Lambsquarter.
CHIN2	*C. incanum* (S. Wats.) Heller	Little goosefoot.
CHLE4	*C. leptophyllum* Nutt.	Slimleaf goosefoot.
CHNA2	*Chrysothamnus nauseosus* (Pall.) Britt.	Rubber rabbitbrush.
CHVI6	*Chrysopsis villosa* (Pursh) Nutt.	Hairy goldaster.
CIUN	*Cirsium undulatum* (Nutt.) Spreng.	Wavyleaf thistle.
CRJA2	*Cryptantha jamesii* (Torr.) Pays.	James cryptantha.
CRMI5	*C. minima* Rydb.	Smallflower cryptantha.
EREF	*Eriogonum effusum* Nutt.	Common buckwheat.
EUGL3	*Euphorbia glyptosperma* Engelm.	Ridgeseed euphorbia.
EVNU	*Evolvulus nuttallianus* Roem. & Schult.	Nuttall evolvulus.
FEOC2	*Festuca octoflora* Walt.	Sixweeks fescue.
GACO5	*Gaura coccinea* Nutt. ex Pursh	Scarlet gaura.
GILA3	*Gilia laxiflora* (Coult.) Osterh.	Gilia.
GUSA2	*Gutierrezia sarothrae* (Pursh) Britt. & Rusby	Broom snakeweed.
HASP2	*Haplopappus spinulosus* (Pursh) DC.	Ironplant goldenweed.
HEPE	*Helianthus petiolaris* Nutt.	Prairie sunflower.
KOSC	*Kochia scoparia* (L.) Schrad.	Kochia.
LAEU	*Lathyrus eucosmus* Butters & St. John	Peavine.
LARE	*Lappula redowskii* (Hornem.) Greene	Redowski's stickseed.
LEDE	*Lepidium densiflorum* Schrad.	Prairie pepperweed.
LEMO4	*Leucocrinum montanum* Nutt.	Common starlily.
LIIN2	*Lithospermum incisum* Lehm.	Narrowleaf gromwell.
LYJU	*Lygodesmia juncea* Pursh (D. Don.)	Rush skeletonplant.
MATA2	*Aster tanacetifolius* H.B.K.[2]	Transyleaf aster.
MILI3	*Mirabilis linearis* (Pursh) Heimerl.	Linearleaf four o'clock.
OECO2	*Oenothera coronopifolia* Torr. & Gray	Combleaf evening primrose.
OPPO	*Opuntia polyacantha* Haw.	Plains pricklypear.

See footnotes at end of table.

TABLE 3.—*Most common plant species on the Sandy Plains Range Site*—Continued

Symbol [1]	Scientific name and author	Common name
ORHY	*Oryzopsis hymenoides* (Roem. & Schult.) Ricker	Indian ricegrass.
OXSE	*Oxytropis sericea* Nutt.	Silky crazyweed.
PLPS	*Plantago purshii* Roem. & Schult. (*P. psyllium* L.)	Wooly Indianwheat.
PSTE3	*Psoralea tenuiflora* Pursh	Slimflower scurfpea.
SAKAT	*Salsola kali tenuifolia* Tausch	Russianthistle.
SEMU4	*Senecio mutabilis* Greene	Groundsel.
SIHY	*Sitanion hystrix* (Nutt.) J. G. Smith	Bottlebrush squirreltail.
SPCO	*Sphaeralcea coccinea* (Pursh) Rydb.	Scarlet globemallow.
SPCR	*Sporobolus cryptandrus* (Torr.) A. Gray	Sand dropseed.
STCO4	*Stipa comata* Trin. and Rupr.	Needleandthread.
THTR2	*Thelesperma trifidum* (Poir.) Britt.	Greenthread.
TOGR	*Townsendia grandiflora* Nutt.	Townsendia.
TROC	*Tradescaneia occidentalis* (Britt.) Smyth	Prairie spiderwort.

[1] Species symbols are standardized according to: SOIL CONSERVATION SERVICE. NATIONAL LIST OF SCIENTIFIC PLANT NAMES. U.S. Dept. Agr., Soil Conserv. Serv., 281 pp. 1971. [Mimeographed.]

[2] Although listed as *A. tanacetifolius* H.B.K. by Harrington (*18*), the National List of Scientific Plant Names lists this species as *Machaeranthera tanacetifolia* (H.B.K.) Nees; hence, the symbol MATA2.

TABLE 4.—*Sources of significant changes in the frequency of occurrence of 27 most common plant species*

[Letters indicate year effects (Y), months of repeated heavy grazing (G), nitrogen fertilization effects (N), and grazing by fertilization interaction (X)]

Group and species	1964	1965	1966	1967	1968	1969	1970
Perennials:							
AGSM					Y		
ARLO3		Y	Y		YGN	YGN	YGN
ASTRA		Y	Y		Y		
BOGR2		Y N	Y	Y N	Y		G
CAFI							
CAHE5	Y	Y	Y		Y	Y	
EREF	Y	Y		Y	Y		Y
GACO5	Y	Y			YG	YG	GN
LYJU					Y		Y
OECO2		Y	Y	Y			
OPPO					YGN	YGN	YGN
PSTE3	Y			Y	Y	Y N	N

TABLE 4.—*Sources of significant changes in the frequency of occurrence of 27 most common plant species*—Continued

[Letters indicate year effects (Y), months of repeated heavy grazing (G), nitrogen fertilization effects (N), and grazing by fertilization interaction (X)]

Group and species	1964	1965	1966	1967	1968	1969	1970
Perennials—Con.							
SPCO			Y	Y	YGN	YGN	YGN
SPCR	Y	Y	Y		Y N	Y	Y N
STCO4		Y	Y	G	G	YG	YG
Annuals:							
CHAL7		Y N	Y N	Y N	Y	YGNX	Y N
CHLE4		Y	Y N	Y N	Y N	YGN	Y N
CHIN2		Y	Y	YGN	Y	YGNX	Y N
CRMI5		Y N	Y N	N	YGNX	YGNX	YGN
EUGL3		Y	Y	Y	Y	Y	Y
FEOC2	Y	Y N	Y	Y	GN	YGN	YG
GILA3	Y	Y	Y	Y	Y		
LARE		Y	Y	Y N	Y N	N	Y N
LEDE	Y N	Y	Y	Y N	YGNX	GN	YGNX
PLPS	Y	Y	Y		Y	YG	YG
MATA2	Y N	Y N	Y N	Y N	YGN	N	YGN
SAKAT		Y N	Y N	Y N	YGNX	YGNX	YGNX

Group and effect	1964	1965	1966	1967	1968	1969	1970	Total
	Number of significant effects on above-mentioned species							
15 perennials:								
Years	5Y	9Y	8Y	5Y	12Y	8Y	6Y	53Y
Months of grazing				1G	5G	5G	6G	17G
N fertilizer		1N			4N	4N	6N	15N
12 annuals:								
Years	5Y	12Y	12Y	10Y	11Y	8Y	11Y	69Y
Months of grazing					5G	8G	6G	19G
N fertilizer	2N	5N	5N	8N	7N	9N	8N	44N
Interaction					3X	4X	2X	9X
Total	12	27	25	24	47	46	45	226

The number of year effects (tables 4 and 5) were larger following a year of unusually low (1964) or high (1967) precipitation. Grazing and fertilization effects increased in number over the years of treatment because a treatment effect, once attained, tended to be residual in subsequent years, especially for perennial species. The responses to N fertilizer greatly exceeded those reported by Klipple and Retzer (*27*).

TABLE 5.—*Mean frequencies of occurrence by species arranged in descending order of mean frequency percentage*

Species	1963	1964	1965	1966	1967	1968	1969	1970	Mean
BOGR2 [1]	80.8	80.1	[2] 66.4	[2] 72.8	[2] 81.0	[2] 82.7	83.2	82.4	78.7
OPPO	48.6	49.0	49.7	49.5	50.1	[2] 40.7	[2] 35.8	[2] 33.3	44.6
SPCO	28.0	27.7	28.0	[2] 31.6	[2] 33.5	[2] 44.1	[2] 46.0	[2] 47.4	35.8
CHLE4	.0	.2	[2] 54.6	[2] 4.9	[2] 59.1	[2] 2.8	[2] 21.5	[2] 42.0	23.1
EREF	24.4	[2] 23.0	[2] 21.7	22.6	[2] 20.1	[2] 22.4	22.5	[2] 23.7	22.6
CAHE5	13.8	[2] 18.5	[2] 12.7	[2] 17.7	17.4	[2] 20.3	[2] 22.5	22.1	18.2
LEDE	.6	[2] 8.5	[2] 31.9	[2] 1.4	[2] 31.4	[2] 15.5	15.9	[2] 38.4	17.9
SAKAT	.0	.4	[2] 21.7	[2] 32.7	[2] 28.7	[2] 19.0	[2] 15.4	[2] 24.5	17.8
FEOC2	.6	[2] 2.4	[2] 15.9	[2] 28.0	[2] 17.9	17.4	[2] 8.8	[2] 46.4	17.2
SPCR	19.0	[2] 11.6	[2] 13.5	[2] 16.7	16.5	[2] 18.5	[2] 22.3	[2] 16.2	16.8
ARLO3	22.5	22.8	[2] 10.0	[2] 12.8	13.3	[2] 15.7	[2] 16.7	17.4	17.4
MATA2	1.3	[2] 6.3	[2] 20.8	[2] 21.9	[2] 17.2	[2] 2.0	2.1	22.6	11.8
CRMI5	.0	.8	[2] 39.9	[2] 9.9	10.2	[2] 7.8	[2] 3.8	[2] 11.5	10.4
PLPS	1.2	[2] 14.1	[2] 7.0	[2] 11.6	11.7	[2] 6.8	[2] 2.3	[2] 14.9	8.7
STCO4	5.4	6.1	[2] 2.6	[2] 6.6	7.4	7.9	[2] 9.0	[2] 11.2	7.0
CHAL7	.0	.1	[2] 15.2	[2] 4.2	[2] 8.5	[2] .3	[2] 3.7	[2] 6.3	4.8
AGSM	4.3	4.1	3.4	4.1	3.9	[2] 5.6	6.3	7.1	4.8
GACO5	4.6	[2] 2.1	[2] 3.2	2.6	3.4	[2] 8.3	[2] 7.0	6.1	4.6
CHIN2	.0	.0	[2] 11.6	[2] .4	[2] 7.5	[2] .3	[2] 3.1	[2] 6.3	3.7
LYJU	3.1	3.0	2.4	2.5	2.3	[2] 4.6	4.7	6.5	3.6
PSTE3	3.4	[2] 1.6	2.3	2.4	[2] 3.5	[2] 5.3	[2] 3.8	4.1	3.3
LARE	.0	.1	[2] 7.6	[2] .5	[2] 2.7	[2] 1.7	2.4	[2] 7.7	2.8
EUGL3	.1	.0	[2] 10.8	[2] .2	[2] 1.5	[2] 5.2	[2] 4.2	[2] .0	2.7
CAFI	2.1	2.2	2.5	2.5	2.4	2.1	2.2	2.5	2.3
GILA3	.6	[2] 1.9	[2] 7.2	[2] 1.8	[2] 3.7	[2] 1.1	.7	1.0	2.2
OECO2	.3	.7	[2] 6.0	[2] .5	[2] 2.8	2.4	2.0	1.5	2.0

ASTRA	.3	.0	[2]10.0	[2]1.7	1.9	[2].6	.5	.4	1.9
CHNA2	2.1	1.7	1.5	1.3	1.4	1.2	1.3	1.7	1.5
MILI3	.6	.5	1.2	1.0	.8	1.7	1.3	2.3	1.2
BUDA	1.8	1.1	.5	.7	.8	1.0	.9	.9	1.0
ASGR3	.9	.7	.5	.7	.8	1.0	1.3	1.4	.9
LEMO4	.9	1.6	.8	.6	.5	.6	.4	1.2	.8
SEMU4	2.6	1.9	.1	.3	.2	.4	.2	.1	.7
KOSC	.0	.1	.1	1.1	.8	1.8	.8	.7	.7
SIHY	.5	.5	.0	.2	.6	1.1	1.1	1.7	.7
TROC	.5	.2	.7	.6	1.0	.9	.5	1.0	.7
CHVI6	1.0	.8	.2	.2	.4	.6	.6	.9	.6
THTR2	.6	.3	.1	.2	.4	1.1	1.1	.8	.6
ALTE	.0	.0	.4	.1	.8	.7	.9	1.4	.5
AGTR	.2	.4	.3	.4	.3	.7	.5	.7	.4
CRJA2	.3	.1	.3	.8	1.0	.3	.2	.2	.4
EVNU	.4	.5	.4	.4	.4	.4	.4	.4	.4
LIIN2	.3	.2	.1	.2	.4	.6	.8	.7	.4
BAOP	.4	.1	.2	.3	.2	.3	.5	.7	.3
CIUN	.4	.2	.1	.2	.4	.5	.5	.7	.3
HASP2	.3	.2	.2	.2	.4	.5	.6	.3	.3
TOGR	.4	.6	.1	.2	.1	.2	.3	.2	.3
GUSA2	.3	.3	.0	.1	.1	.2	.2	1.0	.3
HEPE	.0	.0	.1	.0	.4	.3	.3	.5	.2
ORHY	.0	.1	.2	.3	.3	.5	.4	.2	.2
OXSE	.2	.2	.1	.5	.1	.3	.2	.1	.2
ARFR4	.0	.0	.0	.1	.1	.1	.1	.1	.1
LAEV	.1	.1	.0	.1	.1	.2	.1	.1	.1

[1] BOGR was sampled by 2-inch quadrat and all other species by 16-inch quadrat. Each value is the mean of 24,000 quadrat placements.

[2] Indicates a significant change in frequency since the previous year.

Contrary to some popular conceptions, annual species constituted an important part of the plant community that fluctuated with weather conditions but remained largely independent of grazing treatments. Perennial species, also, were largely independent of grazing. Thus, plant dynamics on the Sandy Plains Range Site of the shortgrass plains was mostly a matter of the amount and seasonal distribution of precipitation.

Weather and Treatment Effects on Perennial Species

BLUE GRAMA

Blue grama, the dominant species and primary forage plant on shortgrass plains, decreased greatly between June 1964 and June 1965 when precipitation was extremely deficient, and increased in 1966 and 1967 when precipitation was well above average (fig. 7). The decreases were significantly greater on fertilized than on unfertilized pastures, but blue grama recovered a little faster with fertilization in wet years.

For many years, blue grama has been known for its tolerance of heavy grazing (*28*). Nevertheless, it is surprising to find that the months of repeated heavy grazing failed to introduce significant effects until 1970, even though weather effects produced big changes on all pastures. Differences among months of grazing are interpreted by the overall mean and smallest significant range (SSR) of 1970 adjusted frequency percentages (fig. 8).

Frequency percentages at or above the upper limit of the SSR are interpreted as positive or increaser-type responses and those at or below the lower limit as decreaser-type responses. Thus, grazing repeatedly in April or June increased blue grama; whereas grazing repeatedly in February decreased blue grama.

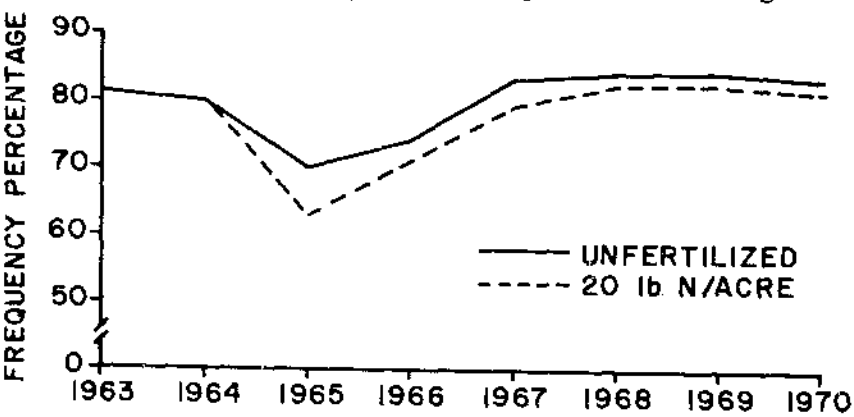

FIGURE 7.—Effects of years and N fertilization on blue grama.

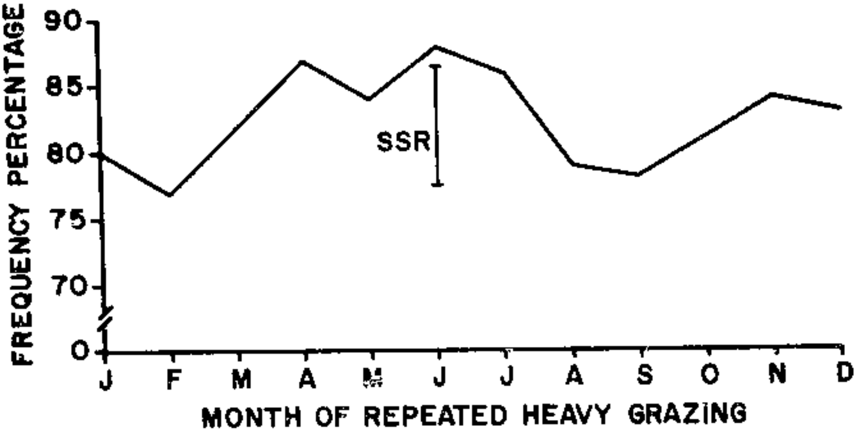

FIGURE 8.—Mean frequency of occurrence of blue grama in 1970 (adjusted by covariance to remove the differences existing in 1963) after 7 years of repeated heavy grazing in different months. The vertical bracket gives the smallest significant range among the 12 means.

July was marginal for increase, and August and September were marginal for decrease. In subsequent comparisons of responses between blue grama and cool-season species, the effects of grazing in September are especially important.

These interpretations of responses to grazing are, of course, relative to the mean frequency prevailing in 1970. Weather conditions largely determined the true changes in frequency percentage from one year to the next, and the treatments eventually modified the effects of weather.

How can a species be sensitive to weather and yet insensitive to heavy grazing? Seedling development places the crowns of blue grama shoots very near the soil surface where adventitious roots must begin. Cloudy, damp weather and a moist soil surface are needed for about 4 consecutive days when the seedlings are 2 to 6 weeks old to permit the extension of adventitious roots. Otherwise, the seedlings die before reaching 9 weeks of age (*24, 46*). These observations indicate an inherent limit to the longevity of blue grama seedlings when they are restricted to the seminal root system, but a more critical evaluation may prove otherwise. Nevertheless, the plants are not permanently established without adventitious roots. This critical need for adventitious roots applies not only to a seedling but to each successive tiller, because the crowns continue to develop horizontally at the soil surface connected in digitate tillering patterns (fig. 9).

Vegetative propagation cannot continue unless successive til-

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FIGURE 9.—Tillering and rooting characteristics of blue grama: *A*, Dead tillering crowns lying horizontally on the soil surface; *B*, adventitious roots below tillering crowns; *C*, exposed tillering crown with live tillers at the front and excised roots from new as well as older parts.

lers establish their own adventitious roots (*19*). Therefore, some crown sequences terminate with unsuccessful tillers while others continue the process of tiller propagation. New digitate patterns of crowns may originate at any point when a tiller is successful in rooting and in propagating two or more new tillers, which in turn are successful in rooting and tiller propagation. The horizontal orientation of crowns prevents excessive elevation of shoot primordia, but the movement of soil from interspaces can leave tillering fronts elevated and exposed. A blue grama seedling is susceptible because damp, cloudy weather is needed when the seedlings are just 2 to 6 weeks old. New tillers on established plants, however, derive support from the parent crown for a much longer time, which improves the chances for weather conditions favoring new adventitious rooting.

The lack of favorable conditions in the growing season of any year can cause the loss of tillers and thinning of stands; whereas, a favorable sequence of weather permits vigorous tillering, rooting, and thickening of stands. New seedlings are rare (*35*), and in the past 40 years workers at the Central Plains Experimental Range have failed to find natural reproduction of blue grama from seed (*25, 28*). Therefore, we attribute stand fluctuations to the success or failure of adventitious rooting by successive tillers.

The relative insensitivity of blue grama to grazing appears to be quite unrelated to its sensitivity to weather. Blue grama has culmless vegetative shoots with short, horizontal crown sections, which prevent the elevation of shoot apices and provide leaf replacement quickly after defoliation or natural curing of leaves (*5,18,38*). When environmental conditions favor growth, leaf expansion continues immediately after defoliation, though probably at a rate slower than previously. Furthermore, defoliation at times of rapid growth, as in June or July, may promote greater tillering and thickening of stands (fig. 8).

No month of repeated heavy grazing was seriously destructive or highly beneficial to the stands of blue grama. Consequently, herbage production is a more important criterion than stand density or frequency for management decisions, unless weather conditions severely reduce the stands.

The stepwise regression of frequency percentages on previous quarterly precipitation amounts helps define the importance of moisture. The regression equations obtained for blue grama stands on unfertilized and fertilized pastures were as follows:

$$\text{Blue grama, unfertilized} = 58.3 + 2.49\ (F\text{–}1) + 1.05\ (S\text{–}1) + 1.18\ (S\text{–}2)$$
$$R = 0.965^{**}$$

Standard error of estimate (SEE) = 2 percent

$$\text{Blue grama, 20 N annually} = 47.5 + 2.90\ (F\text{–}1) + 1.57\ (S\text{–}1) + 1.49(S\text{–}2)$$
$$R = 0.983^{**}$$

SEE = 2 percent

Both equations show that blue grama was favored by precipitation in the summer (*S*–1 and *S*–2) and fall (*F*–1) when soil temperatures were high enough ($>$60 *F* by field observation) to promote vigorous growth and tillering (fig. 10). As shown by the larger regression coefficients in the second equation, precipitation was more essential with N fertilization. Conversely, the lack of precipitation in summer and fall was detrimental to blue grama and could become disastrous, especially with N fertilization.

The equations were derived from frequency data taken in the years 1963 through 1970, and were tested for predictability value for the years 1971 and 1972. Calculated frequency percentages ($\hat{Y}$) correspond closely to observed percentages through 1970 (table 6). Both equations predicted a decrease in blue grama in 1971 and 1972, but both, especially the one for fertilized pastures, fell short of predicting the severity of decrease in 1972. Precipitation in 8 years was too moderate to provide predictive equations sensitive enough to account for the effects of two consecutive summer periods with precipitation at or below half of the 30-year mean (table 1). Nevertheless, conditions that indicate a blue grama frequency in 2- by 2-inch quadrats of less than 70 percent on Sandy Plains and Loamy Plains Range Sites must be considered serious enough to require special consideration in management.

The frequency percentages for blue grama entered into each stepwise regression are means from 12,000 quadrat placements that average out the variability among 48 different stands. Weather conditions were more favorable, or conversely more detrimental, to blue grama in some stands than in others. Severe conditions produced patchy stands of blue grama varying from little to extreme die out. Consequently, the equations are no substitute for sampling. Rather, they are adequate for indicating trend—they can evaluate summer and fall precipitation and pro-

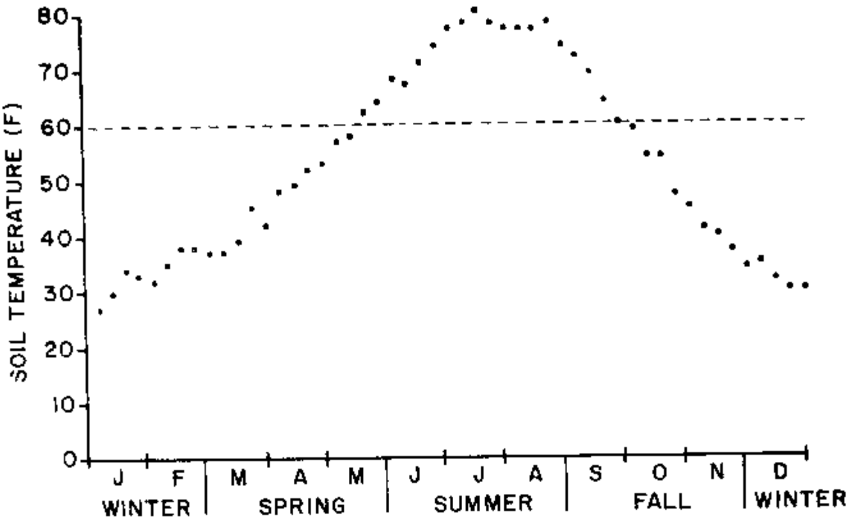

FIGURE 10.—Weekly mean temperatures (*F*) of soil 6 inches below the surface in the 5 years 1967–71. The months are divided into seasons in the manner used to identify quarterly precipitation amounts entered into multiple stepwise regression.

TABLE. 6.—*Frequency percentages for blue grama as calculated by multiple stepwise regression equations* ($\hat{Y}$) *and as observed on unfertilized and fertilized pastures* [1]

Year	Unfertilized		20 lb N/acre annually	
	$\hat{Y}$	Observed	$\hat{Y}$	Observed
1963	81	82	78	80
1964	84	81	81	79
1965	70	70	63	63
1966	75	75	70	71
1967	84	84	80	78
1968	83	84	82	81
1969	83	85	80	82
1970	83	84	80	81
1971	77	82	72	73
1972	70	65	62	61

[1] The regression equations, given in the text, were developed from data obtained in the years 1963–70; therefore, the *Y* values given for 1971 and 1972 predict beyond the data base.

vide a warning when thinner stands may be expected the next summer.

Because N fertilizer increased the severity of drought, it should not be applied following an unusually dry summer and fall. A subsequent section shows that N fertilization can be beneficial in terms of animal production, but it must be emphasized here that the practice is potentially disastrous to blue grama stands.

PLAINS PRICKLYPEAR

Plains pricklypear continued at a frequency percentage of 49 or 50 percent until the wet year of 1967 triggered a significant decreasing trend that was accentuated by N fertilization (fig. 11). Months of repeated heavy grazing, also, introduced significant differences in the last 3 years. As interpreted by the SSR and mean of adjusted frequency percentages in 1970, repeated heavy grazing in September and October increased, and repeated heavy grazing in April and July decreased the stands of plains pricklypear (fig. 12).

The effects appear quite erratic among the months of grazing because the adjusted means for 1970 reveal the net effect of several different weather-by-grazing interactions. Before June 1967, repeated heavy grazing in the warm months May through August contributed to small decreases and repeated grazing in the cool months September through April to small increases (table 7). This seasonal pattern reversed in the wet year of 1967 when grazing in November through April contributed to large decreases and grazing in May through October to only small decreases. In the last 2 years (1968–69), grazing in June and July

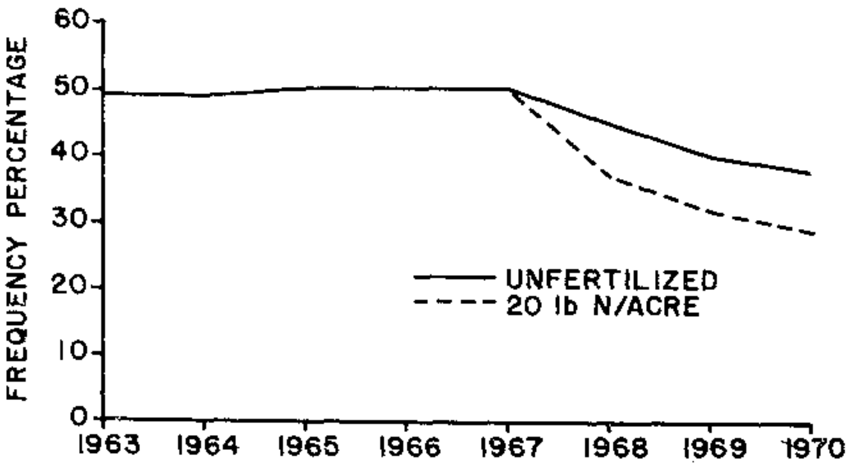

FIGURE 11.—Effects of years and N fertilization on plains pricklypear.

caused larger decreases than grazing in other months. Each of these weather-by-grazing interactions was seasonally discrete, but the net effect was the erratic picture shown in figure 12. Plains pricklypear decreased more on fertilized pastures, but N fertilization did not change the weather-by-grazing interactions.

The large decreases in 1967 appeared to be at least partly caused by insects. Pathogens, also, might have been involved.

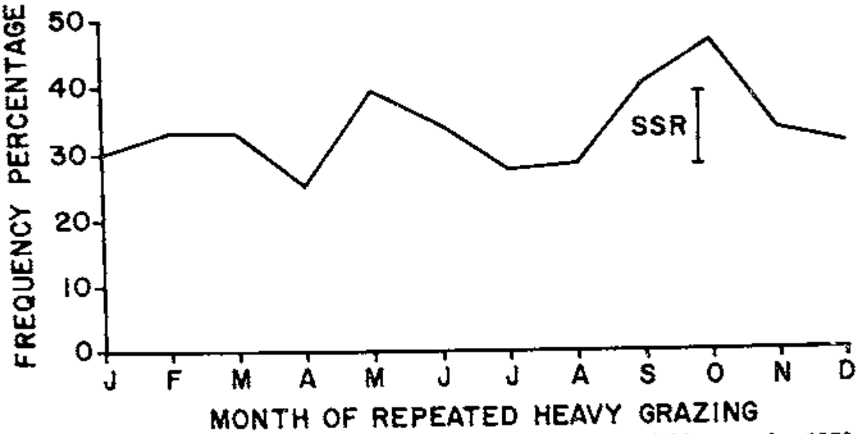

FIGURE 12.—Mean frequency of occurrence of plains pricklypear in 1970 after 7 years of repeated heavy grazing in different months. Compare with figure 8.

TABLE 7.—*Changes in the frequency percentage of plains pricklypear in different years as affected by repeated heavy grazing in different months*

Month of grazing	Changes in frequency percentage from— June 1963 to June 1967	June 1967 to June 1968	June 1968 to June 1970	Total change
January	+1	−18	− 2	−19
February	+3	−15	− 4	−16
March	+2	−12	− 6	−16
April	+1	−16	− 9	−24
May	−1	− 1	− 8	−10
June	0	+ 3	−18	−15
July	−3	− 3	−16	−22
August	−6	− 6	− 9	−21
September	+2	− 6	− 5	− 9
October	+7	− 6	− 4	− 3
November	+4	−17	− 3	−16
December	+3	−17	− 4	−18

Heavy grazing in the cool-season months might have promoted greater infestation of insects and pathogens by reason of trampling injuries to plains pricklypear. In addition, an unusual event was observed shortly after a heavy snow in November 1967. The cattle were eating pricklypear, although with considerable care as indicated by elevated and tossing heads. At that time, pricklypear spines were flexible and lax at the point of attachment to the joints. The recent snow contributed to that condition, but lush growing conditions in the previous summer must have been equally important. At least we have not seen cattle grazing pricklypear in the late fall and winter of any other year, and have been unable to produce the lax condition of spines in laboratory tests.

Stocking heavily in June and July would be most predictably detrimental to pricklypear, perhaps in part because cattle graze the new joints in June and until the spines harden in late July. However, the small benefit in pricklypear control and associated reduction in grass production discount that approach in grazing management. Stocking a pasture heavily for a short period of time in the late fall or winter following an unusually wet season is a better method of reducing plains pricklypear because such treatment should contribute an interaction effect. In addition, an application of not more than 20 lb N/acre in October or November following a wet season should help reduce plains pricklypear. Unfortunately, grazing management alone offers nothing more than a puny attempt at controlling pricklypear. Chemical treatments that provide good control (*1, 41*) may be unprofitable on this rangeland, because pricklypear does not reduce grass production (*2*). Rather, it reduces herbage availability and worries cowboys.

The responses of a single species, such as plains pricklypear, can be quite complex, contrary to the simplification inherent in increaser and decreaser labels (*11*). This complexity is caused by interaction effects that may never become highly predictable. Plains pricklypear has been known traditionally as an increaser or even as an invader, but results from Colorado (*2, 23, 28, 44*) and Montana (*14*) largely refute the assumption of strong grazing effects. Because visual observations of closely grazed and lightly grazed pastures incorrectly convince one that pricklypear is thicker on the closely grazed side, we suspect that the degree of visible perception has contributed to some misconceptions about grazing effects (compare figs. 2 and 4).

The effects of weather on stands of plains pricklypear are at least partly defined by the following regression equations:

$$\text{Plains pricklypear, unfertilized} = 54.4 - 4.19\ (F-1) + 1.52\ (S-1) - 2.61\ (SP-2)$$
$$R = 0.972^{**}$$
$$\text{SEE} = 2 \text{ percent}$$

$$\text{Plains pricklypear, 20 N annually} = 57.9 - 6.81\ (F-1) + 2.44\ (S-1) - 4.98\ (SP-2)$$
$$R = 0.991^{**}$$
$$\text{SEE} = 2 \text{ percent}$$

Both equations indicate that plains pricklypear was favored by a dry spring (*SP*–2), a wet summer (*S*–1), and a dry fall (*F*–1) in the manner characteristic of warm-season species. Consequently, it is misleading and factually incorrect to say that wet years are unfavorable to this species. Above-average precipitation in either spring or fall was unfavorable. However, precipitation in the summer quarter appears as a positive factor throughout the wide range of seasonal amounts received in the years of this study. Plains pricklypear is a distinctly warm-season species that requires precipitation in the summer for growth and propagation by either seed or root sprouts (*44*). Presumably, there would also be an ecological limit to the favorableness of summer precipitation, but such limits are unlikely to be exceeded by natural precipitation on the shortgrass plains.

The stepwise regression equations also provide some insight into the nature of detrimental effects produced by N fertilizer. All three of the regression coefficients are larger in the equation for fertilized pastures. Thus, the negative effects of precipitation in the spring and fall, and positive effects of precipitation in the summer, were all accentuated by N fertilization. The negative effects of precipitation in the fall were accentuated most of all. Consequently, it appears that N fertilizer was detrimental primarily because it extended the growth and physiological activity of plains pricklypear into the fall, if moisture were sufficient, at a time when the plants needed to go dormant in preparation for survival over winter. It remains to be proven that winter survival is the primary factor in the negative effects of N fertilization. Nevertheless, it is suggested that plains pricklypear might be very suitable for physiological studies on cold tolerance. This leads to a further possibility: in the event of above-average rainfall in September, an immediate application of N fertilizer might result in effective control of plains pricklypear.

Calculated and observed frequency percentages for plains pricklypear correspond closely in the 8 years of data used to develop the equations (table 8). Predictive values for 1971 and 1972 indicated further decreases, which were validated by observed values. Above-average spring precipitation and below-average summer precipitation contributed to the continued decrease. In the future, quarterly precipitation amounts may become sufficient to suggest an immediate increase in pricklypear from a frequency percentage in the 20's or 30's to one near 50. Therefore, it is necessary to recognize that pricklypear propagation proceeds gradually even though precipitation changes abruptly and that the equations fail to represent weather conditions that promote an increase in the stands of this species.

TABLE 8.—*Frequency percentages for plains pricklypear as calculated by multiple stepwise regression equations* ($\hat{Y}$) *and as observed on unfertilized and fertilized pastures* [1]

Year	Unfertilized		20 lb N/acre annually	
	$\hat{Y}$	Observed	$\hat{Y}$	Observed
1963	51	49	50	48
1964	50	50	48	48
1965	50	50	49	49
1966	50	50	47	48
1967	49	50	49	50
1968	44	45	35	36
1969	41	40	32	32
1970	38	38	28	28
1971	38	33	29	25
1972	34	35	21	25

[1] Compare with table 6.

The detrimental effects of precipitation in spring and fall on plains pricklypear are interesting from yet another point of view—that of climatic limitations to the distribution of plains pricklypear. Cheyenne, Wyo., is about 15 miles north of the Central Plains Experimental Range, but has a strikingly different seasonal distribution of precipitation. Relative to the Central Plains Experimental Range, Cheyenne has received, by 30-year means, 132 percent as much in the fall quarter, 286 percent as much in the winter quarter, 140 percent as much in the spring quarter, and only 91 percent as much in the summer quarter. The combination of wetter spring and fall quarters and drier summer quarter at Cheyenne should be unfavorable for plains pricklypear, which, indeed, is very scarce on those grasslands (*17*). Cheyenne precipitation amounts, entered into the equation for unfertilized plains pricklypear, indicate an occasional year that should nearly eliminate the species; although by average precipitation amounts, the stands should be about half of those at the Central Plains Experimental Range. Ecologists generally emphasize and describe average weather conditions when considering the adaptability and distribution of a species (*10*). However, this experiment shows that extremes in weather trigger plant responses and should be further evaluated as limiting factors in the adaptability and distribution of a species.

SCARLET GLOBEMALLOW

Scarlet globemallow grows on all of our soils, but by being more abundant on the less permeable upland soils, such as Ascalon sandy loam and Renohill loam, than on the more permeable Vona, Manter, and Greeley sandy loam soils, it is distributed among sites in a manner quite similar to that of plains pricklypear (*23*). Scarlet globemallow is an important component of the diets of insects, small mammals, antelope, sheep, and cattle.[3] Due to its ecological abundance and importance in animal diets, scarlet globemallow is the most important perennial forb, and rates second only to blue grama as a forage plant on some of the upland soils. Consequently, the responses of this species are important considerations in management.

Scarlet globemallow was affected by weather, months of repeated heavy grazing, and N fertilization in that order of importance. The frequency percentage of this species increased

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[3] FLINDERS, J. T., and HANSEN, R. M. DIETS AND HABITATS OF JACKRABBITS WITHIN A SHORTGRASS ECOSYSTEM. U.S. Internatl. Biol. Prog. Grassland Biome Tech. Rpt. 58. 53 pp. 1971. [Mimeographed.]

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greatly from June 1967 to June 1968, when precipitation was greater than recorded in any previous year. N fertilization contributed a little to the increase (fig. 13). In other years, fertilization had no important effects on the stands, but the gain due to fertilization persisted in 1969 and 1970. The effects of months of repeated heavy grazing, also, accumulated in the wet season of 1967 and persisted in 1969 and 1970. Grazing in May or June was most detrimental, and grazing in August or December was most beneficial to this species (fig. 14).

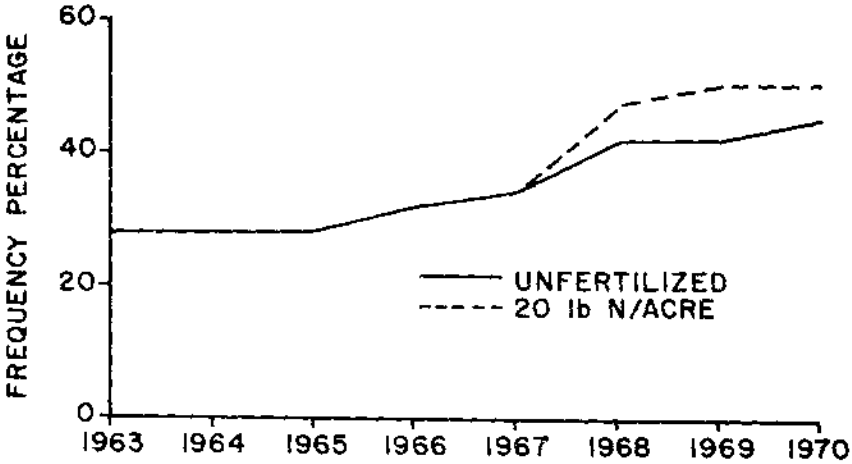

FIGURE 13.—Effects of years and N fertilization on scarlet globemallow.

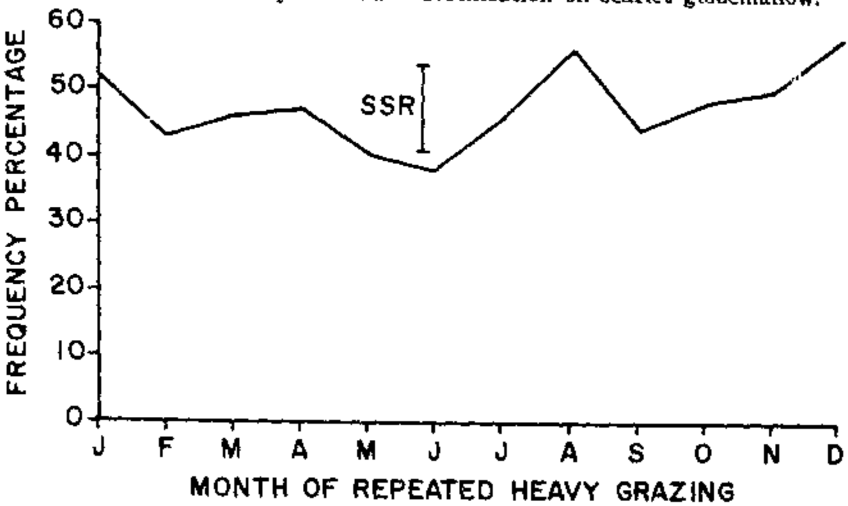

FIGURE 14.—Mean frequency of occurrence of scarlet globemallow in 1970 after 7 years of repeated heavy grazing in different months. Compare with figure 8.

The overall mean frequency percentage increased from 28 percent in 1965 to 48 percent in 1970, indicating a change in density from 0.329 to 0.654 plants per quadrat and a gain of 99 percent in 5 years. Repeated heavy grazing in December produced stands in 1970 with 82 percent more plants than on pastures grazed in June, but N fertilization increased stands by an average of just 16 percent. Weather effects were most profound, but differences due to months of grazing must not be ignored.

Regression equations relate the frequency of occurrence of scarlet globemallow to precipitation as follows:

$$\text{Scarlet globemallow, unfertilized} = 21.4 + 5.53\ (F\text{–}1) - 1.75\ (S\text{–}1) + 3.83\ (SP\text{–}2)$$
$$R = 0.950^{*}$$
$$\text{SEE} = 3 \text{ percent}$$

$$\text{Scarlet globemallow, 20 N annually} = 18.5 + 7.16\ (F\text{–}1) - 2.39\ (S\text{–}1) + 5.40\ (SP\text{–}2)$$
$$R = 0.980^{**}$$
$$\text{SEE} = 3 \text{ percent}$$

Both equations show that scarlet globemallow was favored by a wet spring (SP–2), a dry summer (S–1), and a wet fall (F–1), which is opposite to that for plains pricklypear. Scarlet globemallow responded to precipitation in a manner like that of the cool-season grasses, western wheatgrass, and needleandthread, and may be regarded as a cool-season forb.

Calculated and observed frequency percentages for scarlet globemallow are given in table 9. The predictive $\hat{Y}$ values for 1971 correspond fairly well with observed values, but those for 1972 predicted a substantial increase that failed to materialize. Furthermore, the small advantage due to fertilization disappeared.

Through the 1960 decade, weather conditions permitted an increase by scarlet globemallow even under severe grazing treatment. If weather conditions in the future become generally unfavorable for scarlet globemallow, grazing in May and June could seriously reduce this desirable forb. Scarlet globemallow is subject to temporary growth stoppage in early stages of growth by removal of the apical meristem. Later, when decumbent branches are growing from the main axis, the removal of all apical meristems is unlikely. Also, selective grazing of scarlet globemallow declines in June as blue grama growth accelerates. Consequently, the best plan for protecting declining stands of scarlet globemallow is deferment of grazing in May and perhaps

TABLE 9.—*Frequency percentages for scarlet globemallow as calculated by multiple stepwise regression equations* ($\hat{Y}$) *and as observed on unfertilized and fertilized pastures* [1]

Year	Unfertilized		20 lb N/acre annually	
	$\hat{Y}$	Observed	$\hat{Y}$	Observed
1963	29	28	29	28
1964	31	27	31	29
1965	29	28	29	28
1966	31	32	32	32
1967	30	34	29	33
1968	41	42	46	46
1969	42	43	47	49
1970	46	45	52	50
1971	45	41	50	48
1972	51	44	59	42

[1] Compare with table 6.

also in early June. Heavy grazing in December was favorable to this species, and might be included in the plan for deferment in May. However, the beneficial effect of grazing in December would not necessarily apply under conditions that were generally unfavorable for scarlet globemallow.

SUN SEDGE

Sun sedge, also known as broad-leafed sedge, is a widely distributed perennial species that spreads by rhizomes. It often appears as single shoots scattered among other species. Although the scattered occurrence and short stature prevent selective grazing or rejection by cattle, sun sedge is regarded as a desirable forage plant, especially on the least permeable upland soils in association with blue grama and buffalo grass (*Buchloe dactyloides* (Nutt.) Engelm.) (*23*).

This species responded much less than most other perennials. It fluctuated from a low frequency of 13 percent in 1965 to a high of 22 percent in 1969 (table 5), but failed to respond to either N fertilization or the months of repeated heavy grazing. Sun sedge was favored by a wet fall, a dry winter, and a wet spring, but the multiple-regression coefficient was not significant. This relation to precipitation places it with cool-season species.

Since sun sedge was not responsive to treatments, it cannot serve as a key species in the determination of grazing practices. There is essentially no danger of losing it or opportunity to favor it.

SAND DROPSEED

Sand dropseed is regarded as the best forage plant among the perennial pioneering, or secondary succession, species. As a short-lived perennial, it has adaptive reproductive characteristics equivalent to many annual species. Numerous, small, hard-coated seed exploit the opportunities for establishment. In secondary succession after plowing, sand dropseed becomes subdominant or codominant with red threeawn. Also, it occurs as an important component of "near climax" associations on the most permeable upland soils (*23*).

The frequency of occurrence of sand dropseed dropped from 19 percent in 1963 to 12 percent in 1964, then gradually increased in subsequent years to the highest mean value of 22 percent in 1969 (fig. 15). A dry fall, a wet winter, and a wet spring provided the most favorable sequence in precipitation, but the multiple-regression coefficient was not significant. Precipitation in the winter and spring should contribute to deterioration of hard seedcoats as well as to germination and seedling establishment, because maximum germination has been obtained at an alternating temperature of 5° to 35° C; and prechilling at 5° C for 6 weeks has increased germination by an average 28 percent.[4]

[4] SAYERS, R. L. GERMINATION REQUIREMENTS OF SAND DROPSEED (SPOROBOLUS CRYPTANDRUS) AND SAND LOVEGRASS (ERAGROSTIS TRICHODES). 1968. [Unpublished Ph.D. Thesis. Colo. State Univ., Fort Collins.]

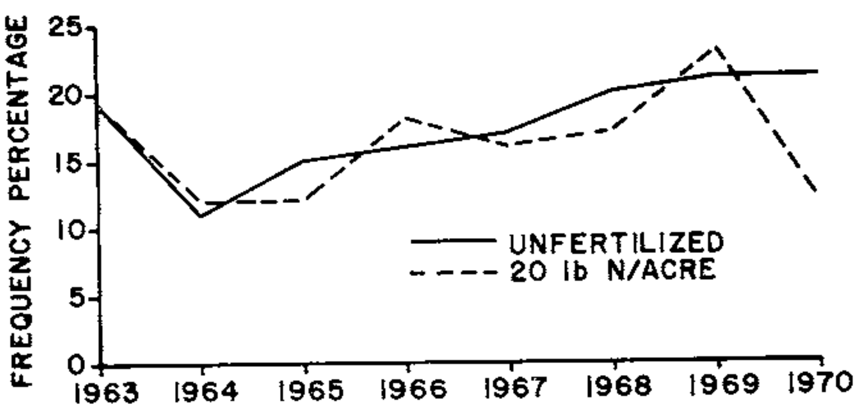

FIGURE 15.—Effects of years and N fertilization on sand dropseed.

Although erratic in effects, N fertilization must be regarded as potentially unfavorable to sand dropseed on the basis of the large detrimental effect that appeared in 1970 (fig. 15). The months of repeated heavy grazing failed to affect this species significantly (P at 0.05); however, even as for blue grama, grazing in June appeared most favorable and grazing in September, especially on fertilized pastures, appeared detrimental to the stands. The coincidence of above-average precipitation in the fall quarter would keep established plants active and susceptible to the detrimental effects of fertilization and grazing; whereas, a dry fall would stop growth and keep the plants nonresponsive. These nonsignificant effects need to be considered because it appears that weather-by-treatment interactions may relate strongly to seed and seedling responses as well as to established plant responses of sand dropseed. Effects on most other perennial species appear to relate almost entirely to the responses of established plants (death and vegetative propagation); and the effects on annuals, only to seed and seedling responses. This added complexity for sand dropseed increases the number of interactions and makes it more difficult to define the net effects of weather, N fertilization, and grazing.

Positive action to increase stands of sand dropseed would be valuable for abandoned plowed fields or for any deteriorated stand of blue grama. Under those conditions, annual species are abundant; therefore, weed control by treatment with an herbicide, such as 2,4-D and heavy grazing in June, should be beneficial. Above all, one should not fertilize with N and graze heavily in September and October when precipitation is sufficient to sustain active growth in the fall.

More importantly, broadcasting seed without tillage or with slight soil disturbance is suggested by the characteristics of this species. The seed can be placed in a forced-air oven at 95° to 100° C for 35 minutes to break dormancy and increase germination.[5] Planting in March is suggested, but other dates should also be considered. Experimental trials are needed to evaluate the possibilities for range improvement by direct seeding of sand dropseed, because any increase in the stand of this species would tend to close the community and decrease the stands of undesirable annual species and of the undesirable perennial grass red threeawn.

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[5] See footnote 4.

RED THREEAWN

Red threeawn was one of the last herbaceous species to be grazed, especially in the summer and fall when the awned seedheads were most objectionable to cattle. Isolated clumps of red threeawn indicated the last phase of grazing, which was terminated when this species was grazed closely. The ecology of red threeawn is fascinating and important because of its low rating as a forage plant and its dominant role in secondary succession on abandoned plowed fields (*9*). Like sand dropseed, it remains an important component of near-climax associations on highly permeable upland soils (*23*). Replacement of red threeawn with more desirable forage species is an important goal in the management of shortgrass ranges.

Red threeawn decreased from a mean of 23 percent in 1964 to 10 percent in 1965, then increased gradually to 22 percent on unfertilized pastures in 1970 (fig. 16). N fertilization prevented the increases.

Months of grazing became significant in the last 3 years, but only on unfertilized pastures. By 1970, red threeawn was greatly favored by repeated heavy grazing in May and suppressed by grazing in July (fig. 17). Grazing in July was as effective as fertilization with 20 lb N/acre in preventing increases in red threeawn following the severe drought in 1964. However, isolated events (interactions) led to the 1970 comparisons among months of grazing. The detrimental effects of heavy grazing in July accumulated almost entirely in the year from June 1964 to June 1965; whereas, the beneficial effects of repeated grazing in May accumulated in the years 1967–68 and 1969–70 (table 10). Thus, the greatest detrimental effect of grazing coincided

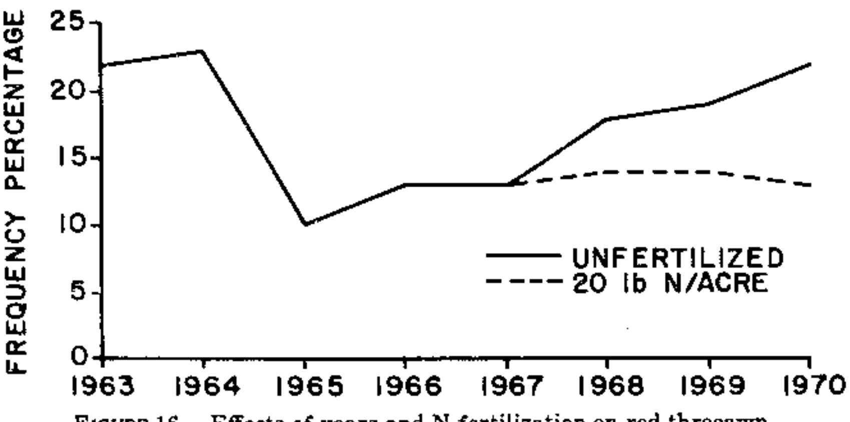

FIGURE 16.—Effects of years and N fertilization on red threeawn.

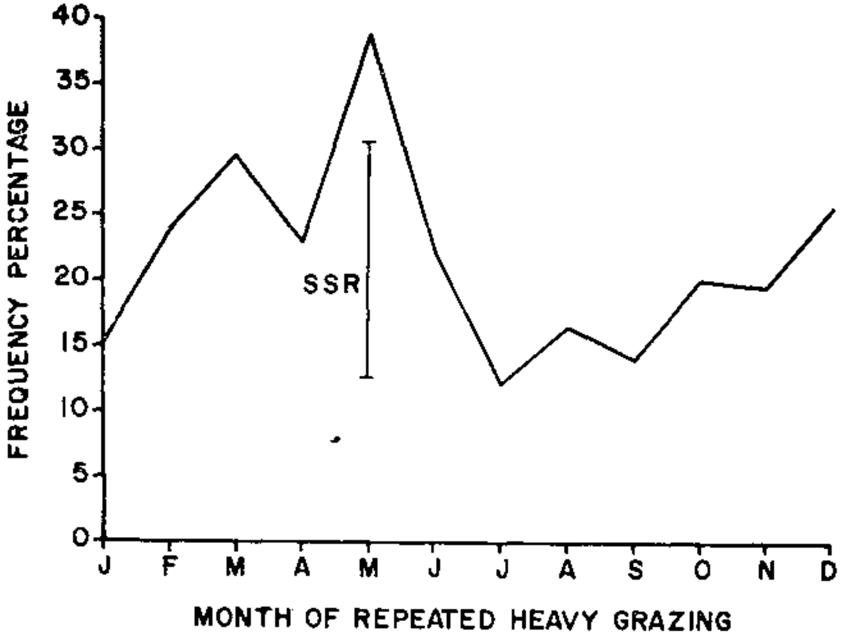

FIGURE 17.—Mean frequency of occurrence of red threeawn on unfertilized pastures in 1970 after 7 years of repeated heavy grazing in different months. Compare with figure 8.

with unfavorable weather, and the greatest favorable effects coincided with favorable weather, which appears to relate primarily to seedling establishment. Such isolated events provide only a weak foundation for describing plant responses to grazing. Weather effects were most profound, followed by the effects of N fertilization, and finally by grazing effects.

The stepwise regression of frequency percentages on quarterly precipitation amounts gives an interesting comparison between unfertilized and fertilized pastures.

$$\text{Red threeawn, unfertilized} = 6.4 - 12.92\,(W\text{–}1) + 1.00(S\text{–}1) + 1.52(F\text{–}2) + 0.90(S\text{–}2)$$
$$R = 0.966^*$$
$$\text{SEE} = 2 \text{ percent}$$

$$\text{Red threeawn, 20 N annually} = 4.1 - 1.66\,(SP\text{–}1) + 1.71\,(S\text{–}1) - 1.57\,(SP\text{–}2) + 1.41\,(S\text{–}2)$$
$$R = 0.976^*$$
$$\text{SEE} = 2 \text{ percent}$$

On unfertilized pastures, red threeawn was favored by a wet summer (*S*–2 and *S*–1), a wet fall (*F*–2), and a dry winter

TABLE 10.—*Annual changes in the frequency percentages of red threeawn on unfertilized pastures as affected by repeated heavy grazing in different months*

Month of grazing	Years							
	1963–64	1964–65	1965–66	1966–67	1967–68	1968–69	1969–70	Sum
January	+1	−16	+3	+2	0	+2	+ 1	− 7
February	+1	−12	+4	+2	+ 1	+3	+ 3	+ 2
March	+4	−11	+5	0	+ 3	+2	+ 5	+ 8
April	+2	− 8	−2	+2	+ 5	+1	+ 1	+ 1
May	+2	−15	+4	+1	[1] +13	−2	[1] +14	+17
June	−3	−11	+4	−2	+ 8	−2	+ 6	+ 0
July	+1	[1] −21	+4	+1	+ 5	0	0	−10
August	−2	−14	+3	+1	+ 7	−1	0	− 6
September	−3	− 9	−1	+1	+ 2	+2	0	− 8
October	+1	−15	+2	+4	+ 2	+1	+ 3	− 2
November	−3	− 9	+2	+1	+ 2	+5	0	− 2
December	+6	−13	+4	+2	+ 1	+4	− 1	+ 3
Average	<+1	− 9	+3	+1	+ 4	+1	+ 3	<− 1

[1] Extreme results that contributed to comparisons obtained in 1970.

(*W*–1). This relation is quite comparable to that of the warm-season grass blue grama. However, on fertilized pastures, red threeawn was favored by a dry spring (*SP*–2 and *SP*–1) and a wet summer (*S*–2 and *S*–1). Because the detrimental effects of N fertilization were associated with above-average precipitation in the spring, it is suggested that N stimulated growth too early in the spring for this warm-season grass. In grasses, N fertilization temporarily mobilizes carbohydrate reserves into growth, leaving plants more susceptible to unfavorable conditions or treatments (*4, 42, 47*). Such stimulation probably could not occur without above-average precipitation in March and April (fig. 6), and perhaps also not without above-average temperatures for a week or more. Though not significant, heavy grazing in April was most detrimental to red threeawn on fertilized pastures.

Observed and calculated (*Y*) frequency percentages for red threeawn on unfertilized and fertilized pastures correspond closely through the 8 years involved in the stepwise regression equations (table 11). Predictive *Y* values for 1971 and 1972 indicate a greater decrease in red threeawn than anything previous. Although the summers of 1970 and 1971 were not so dry as in 1964, they were associated with wet spring weather. That combination was indeed detrimental, though less than predicted by the equations.

There was further evidence that the combination of weather

TABLE 11.—*Frequency percentages for red threeawn as calculated by multiple stepwise regression equations* ($\hat{Y}$) *and as observed on unfertilized and fertilized pastures* [1]

Year	Unfertilized		20 lb N/acre annually	
	$\hat{Y}$	Observed	$\hat{Y}$	Observed
1963	22	22	21	22
1964	20	22	24	23
1965	10	9	9	10
1966	13	12	15	13
1967	12	14	13	13
1968	19	18	13	14
1969	21	19	16	14
1970	21	22	13	13
1971	10	15	6	10
1972	5	10	−5	4

[1] Compare with table 6.

events in 1970 and 1971 was detrimental to red threeawn. An abandoned plowed field in a section of land adjacent to these experimental pastures was dominated by red threeawn (over 90 percent frequency of occurrence in 16- by 16-inch quadrats) from the time of Costello's (*9*) report on secondary succession until 1971. However, in June 1972 the mean frequency percentage of red threeawn in 20 macroplots, each of 250 quadrat placements, was just 39 percent, which indicates a loss of about 80 percent of the stand on a density basis.

The possibility of controlling red threeawn on abandoned cropland with ammonium nitrate has been reported (*25*). Low rates of N fertilizer followed by heavy grazing in April, and possibly the direct seeding of sand dropseed, appear to offer the best chance for reducing red threeawn and increasing forage production on abandoned croplands.

COMMON BUCKWHEAT

Common buckwheat, sometimes referred to as a half shrub because of its woody base, is essentially restricted to the more permeable soils exemplified by those selected for this experiment (*23*). It was quite uniformly and conspicuously distributed over most of the 48 pastures. Although the cattle never exhibited any particular preference for common buckwheat, the heavy grazing treatments generally attained close utilization of all perennial species except plains pricklypear. Frequencies of common buckwheat fluctuated among years from a mean of 20 to 24 percent (table 5), but were unaffected by fertilization and the months of repeated heavy grazing. Consequently, it was the least responsive of subdominant perennials. This lack of fluctuation in frequency prevents the detailed consideration of plant responsiveness. Decreases in stands would likely be very slow for this long-lived species, but the plants appear to produce a large number of small seed, which might contribute to a rapid increase in some situations. Because heavy grazing at any time of year might destroy new seedlings, the lack of responsiveness might of itself be due to grazing treatments. In any event, the ecology of common buckwheat is apparently quite immaterial in the management of shortgrass range.

NEEDLEANDTHREAD

Needleandthread, which is largely restricted to the most permeable upland soils at the Central Plains Experimental Range (*24*), started in 1963 at a mean frequency percentage of about 5 percent (fig. 18). The drought in 1964 reduced stands to

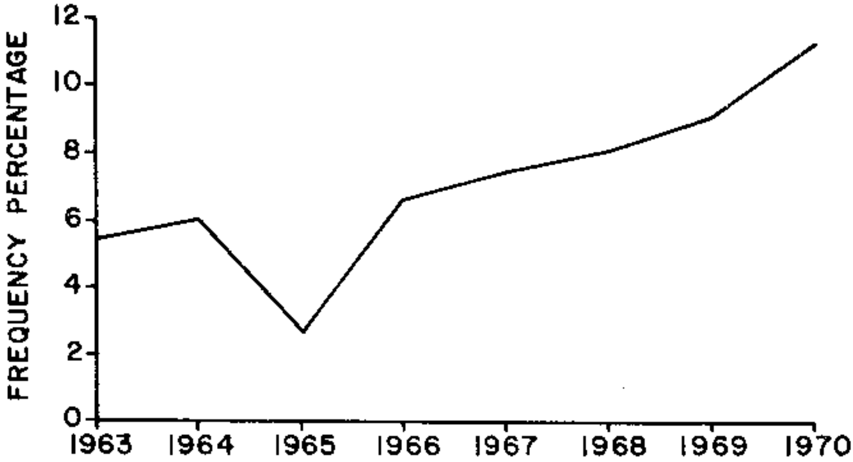

FIGURE 18.—Effects of years on needleandthread.

slightly less than 3 percent by June 1965, but more favorable conditions in subsequent years increased stands to 11 percent by June 1970. Needleandthread is a cool-season grass that responds to precipitation in the spring and fall. Its recovery from the drought in 1964 was associated with above-average precipitation in cool-season months September 1965; August and September 1966; April and May 1967; May 1968; April, May, September, and October 1969; and March and April 1970 (fig. 6). Although individual plants generally grew better with fertilization, N applications did not affect stands in any year.

The stepwise regression of frequency percentages on quarterly precipitation amounts shows the cool-season requirements of needleandthread.

$$\text{Needleandthread} = 0.9 + 2.42\,(F\text{–}1) - 0.34\,(S\text{–}1) + 0.83\,(SP\text{–}2)$$
$$R = 0.978^{**}$$
$$\text{SEE} = <1 \text{ percent}$$

This species was favored by a wet spring (*SP*–2), a dry summer (*S*–1), and a wet fall (*F*–1). The equation looks good even in predicting frequency percentages for 1971 and 1972 (table 12). Unfortunately, the equation is not suited to other sites or locations where needleandthread is a more important component of the vegetation.

Needleandthread is taken by cattle most readily in the spring and fall and least readily in the summer when the awns interfere with utilization and injure cattle. Its lack of tolerance

TABLE 12.—*Frequency percentages for needleandthread as calculated by multiple stepwise regression equation* ($\hat{Y}$) *and as observed in different years* [1]

Year	$\hat{Y}$	Observed
1963	5	5
1964	6	6
1965	3	3
1966	6	6
1967	7	7
1968	8	8
1969	8	9
1970	12	11
1971	10	11
1972	10	11

[1] Compare with table 6.

for excessive defoliation has been reported many times (*23*, *34*, *39*, *50*). In the present experiment, significant differences among months of grazing appeared in 1967, which was earlier than for any other perennial species (table 4). By 1970, those differences were outstanding (fig. 19). However, the relatively high frequency percentage on pastures grazed in May is the result of some coincidence of weather and treatment in the final year of study (table 13). Excepting that isolated event, the frequency for May pastures should lie between those for April and June as indicated by a short dotted line and circle in figure 19. Thus, we conclude that repeated heavy grazing in April, May, June, and July was adverse to needleandthread. Grazing in December or March was most beneficial (least harmful), but these effects were not so consistent through the years as that of close utilization in June or July.

These data indicate essentially no basis for positive action to increase the stands of needleandthread. Although we would not want to increase this species in a good stand of blue grama, it is distinctly preferable to red threeawn on abandoned plowed fields. In that case, a management plan should be designed to prevent overuse in April, May, June, and July. As with other cool-season species, cattle even at light stocking rates may overutilize the early growth of needleandthread. By June, the growth rate of forage species generally exceeds the rate of harvest with light or moderate stocking rates (*3*). Consequently, management to favor cool-season species involves primarily the prevention of overuse in April and May by deferring grazing or stocking lightly.

Although close utilization in June is detrimental to stands of needleandthread, a quick, moderate cropping in early June, when

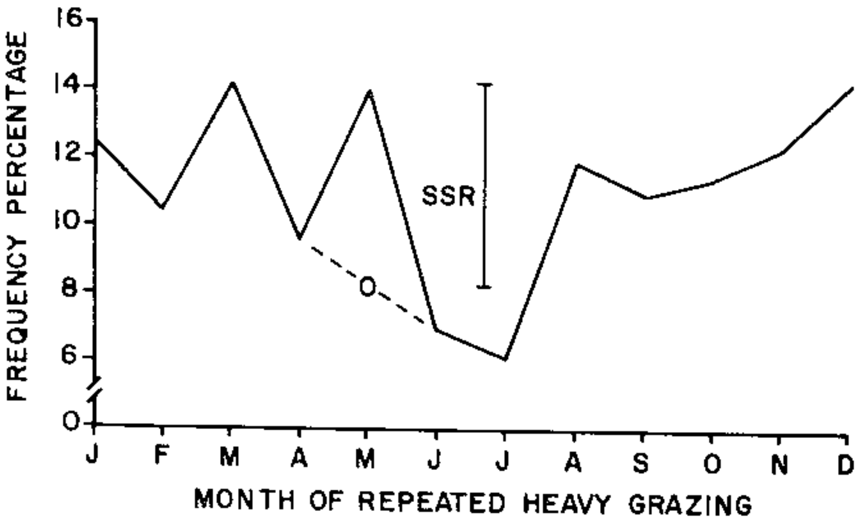

FIGURE 19.—Mean frequency of occurrence of needleandthread in 1970 after 7 years of repeated heavy grazing in different months. Compare with figure 8.

TABLE 13.—*Annual changes in the frequency percentage of needleandthread as affected by repeated heavy grazing in different months*

Month of grazing	Years						
	1963–64	1964–65	1965–66	1966–67	1967–68	1968–69	1969–70
January	+3	−5	+5	+2	0	+2	0
February	+1	−4	+4	+4	−2	+1	+1
March	+3	−5	+5	+2	+1	+1	+2
April	0	−2	+2	0	+3	−1	+3
May	−1	+1	+2	−4	+1	+2	+8
June	−1	−1	+1	0	0	0	+3
July	+1	−7	+5	0	+2	0	0
August	+1	−4	+6	0	0	+2	+2
September	+1	−2	+2	+3	−1	+1	+2
October	0	−3	+4	+2	0	+2	+1
November	+1	−3	+5	0	+3	0	+1
December	+2	−4	+5	+2	0	+3	+1

the heads are in the boot stage of development, can remove the heads and prevent subsequent interference and injury to cattle by awns. For this purpose, the timing and degree of use must be determined on limited areas, preferably when soil moisture is adequate for good regrowth, and should be followed by a period of deferment. With good growing conditions, needleandthread can produce a desirable, leafy regrowth in early summer.

WESTERN WHEATGRASS

Western wheatgrass varied from a mean frequency of 4.3 percent in 1967 to 7.1 percent in 1970 (table 5). It is a relatively unimportant species on this shortgrass rangeland because good growth and rhizome development is prevented by deficiency in precipitation in the spring and fall. The importance of spring and fall precipitation is shown by the stepwise regression of frequency percentages on quarterly precipitation amounts, as follows:

$$\text{Western wheatgrass} = 2.1 + 1.06\,(F\text{–}1) - 0.28\,(S\text{–}1) + 0.66\,(SP\text{–}2)$$
$$R = 0.982^{**}$$
$$\text{SEE} = 0.4 \text{ percent}$$

Like other cool-season species, western wheatgrass was favored by a wet spring (*SP*–2), a dry summer (*S*–1), and a wet fall (*F*–1).

The frequency of western wheatgrass in 16- by 16-inch quadrats was too small in most pastures to provide an adequate sample. Patchy distribution and propagation by rhizomes contributed to the sampling problem. Experimental treatments created nonsignificant (P at 0.05) trends toward increase of western wheatgrass with N fertilization, decrease with grazing in June, and increase with grazing in September. Those trends, though not significant, are worthy of consideration as a basis for further research on sites more favorable to this species.

Among the adjusted means for 1970, the frequencies were 5.6 and 8.5 percent for unfertilized and fertilized pastures, indicating a stand increase of about 66 percent with 20 lb N/acre annually. With frequencies of 4.9 and 15.2 percent for grazing in June and September, respectively, the responses to grazing greatly exceeded those to fertilization and weather. These trends are comparable to those reported from the Northern Great Plains where western wheatgrass is one of the most important forage species (*8*, *15*, *31*, *36*, *37*, *49*).

The trends for decrease of western wheatgrass with grazing in June and increase with grazing in September is opposite to the responses by blue grama. Therefore, where these two species are about equally well adapted, their composition might be varied at will by changing the season of use. Pastures dominated by western wheatgrass are more suitable for grazing in the spring and early summer, and those dominated by blue grama are more suitable for grazing in the summer, fall, and winter. However, grazing at those times should reverse the composition and eventually require reversal in order of use to maintain preferred forage.

Rather than manage grazing to change the composition of these two grasses back and forth, one might prefer to maintain a desirable balance between them. Annual or biennial changes in the seasons of grazing should help maintain a balanced composition. Stands considered out of balance might be improved with a treatment of heavy grazing in June to increase blue grama or of heavy grazing in September to increase western wheatgrass. Of course, heavy grazing in September seems less desirable than N fertilization for increasing western wheatgrass on the Northern Great Plains (*31, 37*).

Differences in the seasonal distribution of precipitation between the Central Plains Experimental Range and Cheyenne, Wyo., were considered as important to the distribution of plains pricklypear, and may be considered equally important for western wheatgrass. The greater amounts of precipitation in the spring and fall quarters, and lesser amount in the summer quarters, at Cheyenne, should be favorable to western wheatgrass as well as unfavorable for plains pricklypear. Western wheatgrass occurred infrequently under the marginal conditions at the Central Plains Experimental Range but was found to occur at a frequency of 82 percent in 16- by 16-inch quadrats near Cheyenne (*17*). These comparisons substantiate the general interpretation of the stepwise regression equations even though the regression coefficients do not represent conditions and responses at other locations.

SCARLET GAURA

Although scarlet gaura was the second most important perennial forb, it was such a minor component of the vegetation that it justifies nothing more than a low level of priority in grazing management. Scarlet gaura fluctuated from a frequency of 2 to 8 percent among years and remained independent of N fertilization until 1970 (fig. 20). The importance of precipitation to

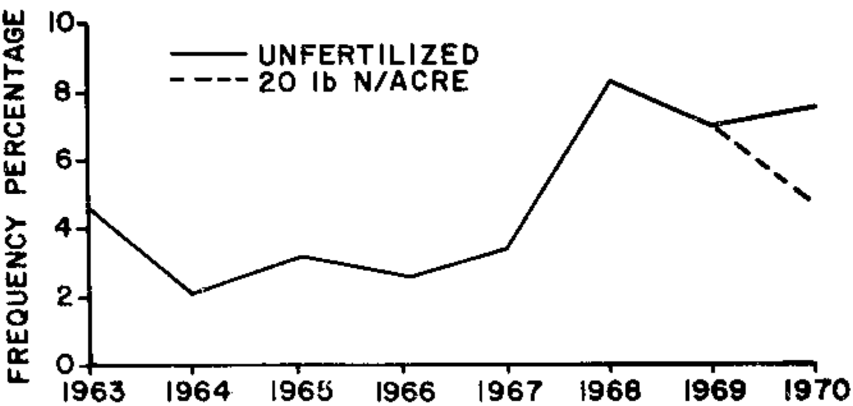

FIGURE 20.—Effects of years and N fertilization on scarlet gaura.

stand fluctuations among years is shown by the following equation:

$$\text{Scarlet gaura} = 0.60 + 0.60\,(SP\text{–}1) - 2.99\,(W\text{–}1) + 0.90\,(SP\text{–}2)$$
$$R = 0.973^{**}$$
$$\text{SEE} = 0.7 \text{ percent}$$

Thus, scarlet gaura was favored by a dry winter (*W*–1) and a wet spring (*SP*–2 and *SP*–1). These favorable conditions must relate almost entirely to seedling establishment because the species has no apparent mechanism for vegetative propagation, and the equation must account for the large increase recorded in 1968.

The months of repeated heavy grazing introduced significant effects coinciding with the increase of 1968 and persisting in 1969 and 1970. Grazing in June, July, or August prevented the increase; whereas, grazing in May or September was most favorable (fig. 21). Because these effects originated only in the year that promoted good increases, we presume that grazing in June, July, or August prevented seedling establishment. Over the years, repeated heavy grazing in June was most consistently detrimental, but established plants seemed to endure the rigors of weather, repeated heavy grazing, and N fertilization remarkably well.

OTHER PERENNIAL SPECIES

Rush skeletonplant was a minor component that responded slightly to year effects (table 5), but nonsignificantly to N fertilization and the months of repeated heavy grazing (table 4).

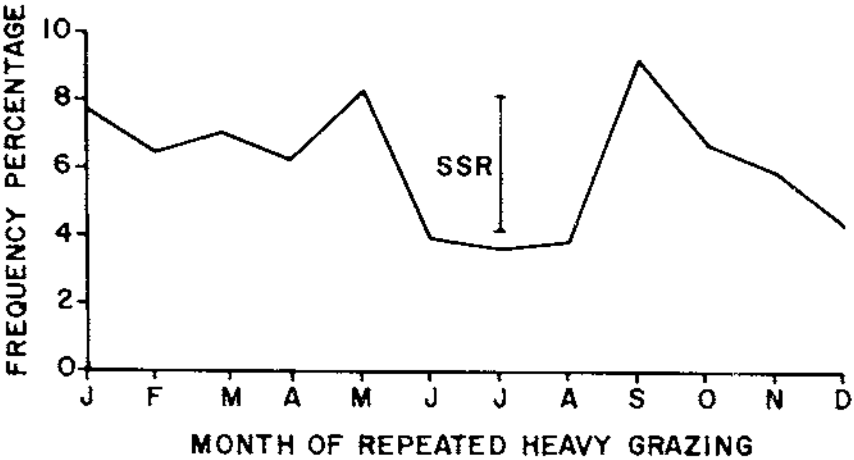

FIGURE 21.—Mean frequency of occurrence of scarlet gaura in 1970 after 7 years of repeated heavy grazing in different months. Compare with figure 8.

Trends suggest that fertilization might be slightly detrimental and repeated heavy grazing in May slightly favorable.

Slimleaf scurfpea was the most valuable legume, but contributed little to the forage crop. Generally, the cattle passed it by except in the late summer and early fall when blue grama was dry and slimleaf scurfpea still green. Frequencies of slimleaf scurfpea fluctuated significantly from 1.6 percent in 1964 to 5.3 percent in 1968 (table 5). Although large in relative terms, those changes were unimportant in quantitative terms. N fertilization created significant, but ecologically small, negative effects in 1969 (frequencies were 4.5 and 3.0 percent on unfertilized and fertilized pastures, respectively) and this difference was sustained in 1970. Months of repeated heavy grazing were nonsignificant in all years. A significant stepwise regression of frequency percentages on quarterly precipitation amounts shows that slimleaf scurfpea was favored by a dry winter and a wet spring. Thus, the general deficiency of precipitation in the spring may account for its minor role in the community.

The entry identified only to the genus *Astragalus* and called milkvetch included seedlings and small established plants that could not be identified to species but appeared to be mostly *A. missouriensis*. Frequencies for milkvetch fluctuated significantly among years (table 5), but remained independent of fertilization and grazing treatments. Several *Astragalus* species were found on the 48 pastures. *A. gracilis*, *A. striatus*, and *A. mollissimus* were the other common species. All together they were encountered at a frequency of less than 10 percent. The total legume component, including the genera *Psoralea, Astragalus, Oxytropis, Lupinus,* and *Lathyrus,* was so scarce in most stands that it seems unlikely that their contribution by N fixation would be of appreciable importance. Their contribution to the forage crop is easily ignored.

Combleaf evening primrose is another desirable forb that is well worth keeping and increasing. Although its responses to weather conditions were large in relative terms, its stands were always very thin. N fertilization and months of repeated heavy grazing were immaterial to this species.

Threadleaf sedge is conspicuous because it grows in dense sod islands that change slowly in size. Cattle nearly always graze threadleaf sedge closely, but the species appeared completely nonresponsive to weather, N fertilization, and months of repeated heavy grazing in terms of its frequency of occurrence.

Weather and Treatment Effects on Annual Species

SLIMLEAF GOOSEFOOT

Annual species have been rated theoretically as indicators of deterioration in range condition on the Central Great Plains. Slimleaf goosefoot provides a good test of that theory. Frequencies of slimleaf goosefoot fluctuated between 0 and 55 percent on unfertilized pastures and between 0 and 78 percent on fertilized pastures (fig. 22). The initial increase in 1965 coincided with reduction of blue grama, but subsequent fluctuations of slimleaf goosefoot were essentially unrelated to the stands of blue grama or, in fact, to the stands of any perennial, or any combination of perennials. Consequently, its role as an indicator of deterioration in range condition is questionable. Further evaluation requires the consideration of environmental factors such as soil moisture and fertility status as driving forces for change in botanical composition.

The responses to N fertilization (fig. 22) show the importance of available soil nitrate as a driving force. In addition, the seasonal distribution of precipitation appears as a driving force in the stepwise regression of frequencies on quarterly precipitation amounts.

$$\text{Slimleaf goosefoot, unfertilized} = 62.0 + 6.16\,(SP\text{–}1) - 6.49\,(S\text{–}1) - 2.88\,(S\text{–}2)$$
$$R = 0.968^{**}$$
$$\text{SEE} = 7 \text{ percent}$$

$$\text{Slimleaf goosefoot, 20 lb N/acre annually}$$
$$= 52.2 + 8.20\,(SP\text{–}1) - 4.44\,(S\text{–}1) - 27.05\,(W\text{–}2)$$
$$R = 0.864$$
$$\text{SEE} = 22 \text{ percent}$$

The equation for unfertilized pastures shows that slimleaf goosefoot was favored by previous dry summers (*S*–2 and *S*–1) and a wet spring (*SP*–1). This species disseminates seed in late fall and winter when temperatures are too cold for germination. It is a fairly typical summer annual that requires a favorable amount and distribution of precipitation in the spring for germination and establishment. But why should it be favored by previous dry summers? This must surely be an indirect effect that cannot be explained by the data obtained. However, it may be suggested that the fertility status of the soil improved in dry summers.

Concentrations of available nutrients in the soil, especially of N and P, fluctuate seasonally, generally reaching peak levels early in the growing season. Uptake by plants and soil microorganisms and leaching decrease the nutrient concentrations during the growing season even though the processes of mineralization continue simultaneously. With below-average precipitation and a short growing season, nutrient uptake, leaching, and mineralization are relatively small, making possible a net gain in

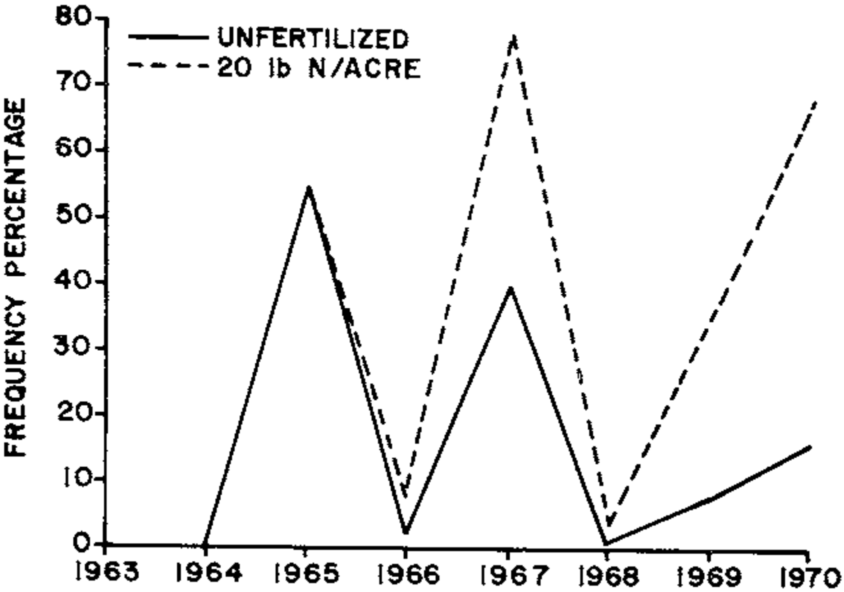

FIGURE 22.—Effects of years and N fertilization on slimleaf goosefoot.

the carryover of available nutrients. Furthermore, nitrate ions rise in capillary streams and accumulate near the soil surface during long dry periods according to Wetselaar (*48*). Under the climatic conditions of the Central Great Plains, the proportionately large losses of moisture by evaporation from the soil surface might cause similar accumulations of nitrate near the surface.

As shown by the stepwise regression equation for unfertilized pastures and by stand fluctuations among years (fig. 22), the most limiting factor was moisture for germination and establishment in the spring. When moisture was sufficient for abundant germination, the number of established plants increased greatly with N fertilization. Thus, on unfertilized pastures, previous dry summers probably permitted more carryover of available N than was possible following wet summers and abundant plant growth. Such details regarding fluctuations in moisture and fertility status must be involved in, but are not exclusive to, changes in range condition. Specifically, slimleaf goosefoot does not indicate deterioration in range condition. Rather, it indicates favorable environmental conditions, which may or may not be associated with deterioration in range condition. This fact could be repeated for all other annuals.

The stepwise regression equation for fertilized pastures also shows the importance of a previous dry summer and wet spring, but includes precipitation in a previous winter (W–2) as a negative component. However, the multiple correlation coefficient was not significant, and the standard error of estimate was 22 percent. N applications reduced the relative importance of precipitation and might have had a variable effect on seed production and viability.

Stands of slimleaf goosefoot were affected significantly by the months of repeated heavy grazing only in 1969. The stands obtained in that year were reduced greatly by the treatments of heavy grazing in May and June compared with grazing in other months. Because the stands were very thin throughout in 1968, those effects of grazing in May and June probably were not residual from treatments imposed in 1968. Thus, there is no obvious explanation of why heavy grazing in either May or June would be so detrimental in 1969 and not in other years that were favorable to slimleaf goosefoot. May to June is about the only time when cattle can be forced to graze this species. Close utilization of slimleaf goosefoot in May or June generally leaves plenty of time for regrowth and seed production, but may not have done so in 1969.

Slimleaf goosefoot is not a desirable forage plant. Furthermore, it tolerates very high concentrations of nitrate in the soil (*25*) and is potentially hazardous in terms of nitrate accumulation and toxicity to animals (*16*). Thick stands appearing in May have been controlled with an application of 2,4-D at 1 lb/acre applied in late May or early June.

RUSSIANTHISTLE

Russianthistle was very scarce (frequency less than 1 percent) in 1963 and 1964, then increased abruptly in 1965, and sustained fair stands through 1970 (fig. 23). It responded more consistently and abundantly to N fertilization and to the months of repeated heavy grazing than other annual species.

N was a significant factor in each of the last 6 years. By average, the frequencies were 9 and 40 percent for unfertilized and fertilized pastures, indicating a greater than fivefold increase in number of plants. Such increase by fertilization was reported previously by Klipple and Retzer (*27*).

Months of repeated heavy grazing were significant in the last 3 years, but only on fertilized pastures (fig. 24). This difference between fertilized and unfertilized pastures appeared as a significant interaction between fertilization and months of grazing. On fertilized pastures, grazing in November, December, January, and February was most favorable to Russianthistle, and probably helped by planting the seed, which germinates better when covered with mineral soil (*45*). Grazing in March, April, and May, at the time of seed germination and seedling establishment, was detrimental to stands. The second low point in figure

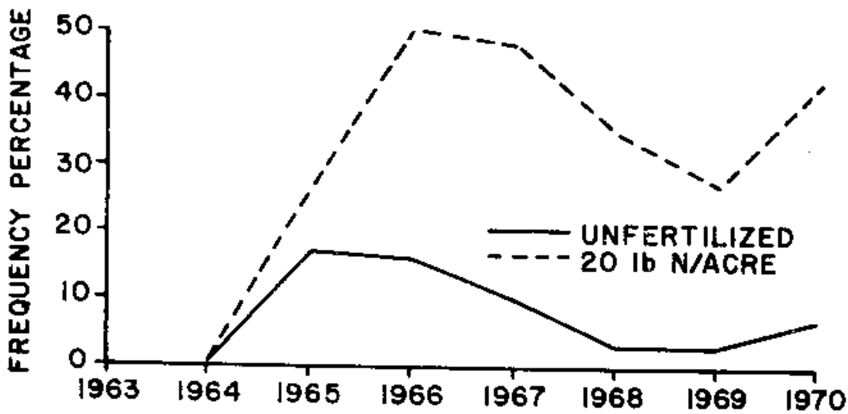

FIGURE 23.—Effects of years and N fertilization on Russianthistle.

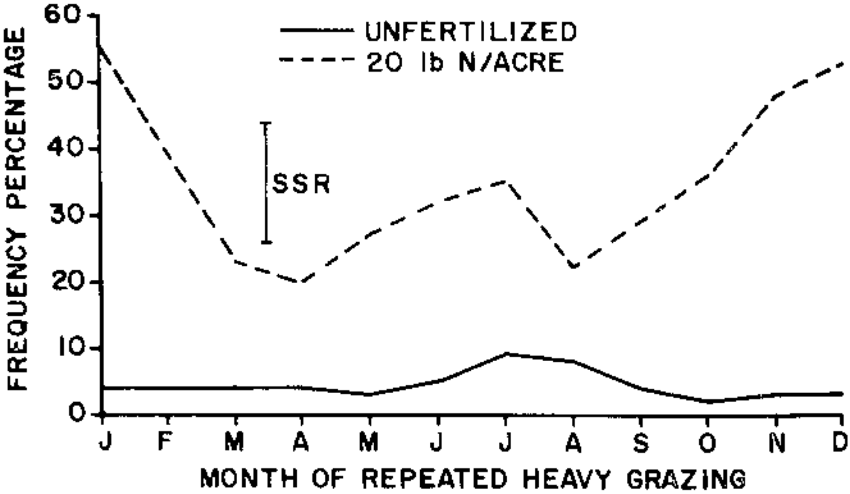

FIGURE 24.—Mean frequency of occurrence of Russianthistle averaged across the years 1968–70 to show the mean effects of repeated heavy grazing by individual months on unfertilized and fertilized pastures.

24 reflects the lack of regrowth and seed set after grazing in August. These grazing effects did not persist from year to year as with perennial species; therefore, figure 24 presents mean frequencies averaged across the years 1968–70. Only small variations occurred among those years in the seasonal pattern of grazing effects.

Russianthistle flowers in July and develops fruit in late August. The mature seeds shatter primarily in early winter when temperatures are too cold for germination. Russianthistle, like slimleaf goosefoot, is a summer annual, but appears to germinate at least a month before slimleaf goosefoot. Stevens (*40*) reported germination in April. Therefore, it is not surprising to find dependence on winter and spring precipitation in the stepwise regression equations.

$$\text{Russianthistle, unfertilized} = 30.0 + 8.33\,(W\text{–}1) - 1.82\,(S\text{–}1) - 1.88\,(S\text{–}2)$$
$$R = 0.962^{**}$$
$$\text{SEE} = 2 \text{ percent}$$

$$\text{Russianthistle, 20 lb N/acre} = 53.8 + 7.96\,(SP\text{–}1) - 13.16\,(F\text{–}2) - 3.43\,(S\text{–}2)$$
$$R = 0.923^{*}$$
$$\text{SEE} = 10 \text{ percent}$$

On unfertilized pastures, Russianthistle was favored by previous dry summers (*S*–2 and *S*–1) and a wet winter (*W*–1). Presumably, both winter and early spring precipitation would favor annual species that germinate soon after melting of snow and thawing of frozen soil. Previous dry summers were beneficial presumably because of greater carryover of available N in the soil. This effect on seedling establishment, however, should not be confused with the positive effect of summer precipitation on plant growth and herbage yield.

On fertilized pastures, Russianthistle was favored by a previous dry summer (*S*–2), a previous dry fall (*F*–2), and a recent wet spring (*SP*–1). When judged in terms of the size of *F* to remove from stepwise regression, the wet spring was far more important than the dry summer and dry fall.

Russianthistle is a desirable forage plant, best among the common annuals, and is grazed readily by cattle in late summer and fall after the grasses dry up. It remains succulent later than most species and stimulates forage intake and rate of passage through the animals. Its digestibility and feeding value are not especially good even though its crude protein concentrations generally exceed those of grasses (*6, 7, 33*). Because plants grown in a good stand of blue grama generally are short, they seldom tumble before the wind to lodge in fences and create a nuisance.

Plants having growing points elevated by stem elongation are most susceptible to reduction in growth by grazing in the growing season. However, Russianthistle evades serious reduction in yield by branching abundantly. The lowermost branches curve outward and remain temporarily decumbent. This form of growth keeps many growing points and axillary buds below the reach of cattle.

To promote an increase in Russianthistle, one should apply N fertilizer at 15 to 20 lb N/acre. In addition, stocking heavily in the winter for 1 or 2 years would help develop a good seed supply. Thereafter, moderate to slightly heavy grazing in August and September would harvest maximum return from the practice. Though somewhat less profitable, moderate stocking and continuous grazing from about June 1 to November 1 is also appropriate, and certainly more acceptable to small ranches than concentrated grazing in August and September.

Unfortunately, it is not possible to manage for an increase in Russianthistle without also increasing slimleaf goosefoot and other undesirable annual species that respond positively to N fertilizer.

SIXWEEKS FESCUE

Next we consider the most undesirable annual species, one that cattle try to avoid by choosing fescue-free areas and by grazing carefully around the fescue plants encountered (*21*). Nevertheless, the plants are not always avoided, and when included in a bite they are pulled up with considerable soil attached. Such plants are dropped, sometimes with most of the bite of blue grama. Thus, the avoidance and rejection of sixweeks fescue greatly interferes with the utilization of blue grama.

Sixweeks fescue is a winter annual (*26*). Therefore, it is not surprising to find that fluctuations among years were dependent on precipitation in the fall. The stepwise regression, including data from all treatments, was as follows:

$$\text{Sixweeks fescue} = 34.3 + 4.16\,(F\text{–}1) + 2.73\,(SP\text{–}2) - 24.01\,(W\text{–}2) - 2.89\,(S\text{–}2)$$
$$R = 0.874$$
$$\text{SEE} = 11 \text{ percent}$$

Sixweeks fescue was favored by a dry summer (S–2) followed by a dry winter (W–2), a wet spring (SP–2), and finally a wet fall (F–1). This relation is quite complex and nonsignificant because it must average out the interactions of weather and treatments on the processes of seed production, germination, and seedling establishment. N fertility rates were not held separate because fertilization caused small and variable results among years (fig. 25). The most important part of the sequence began with a wet spring for good plant growth and seed production. Then precipitation in the fall was important for germination and establishment of a new stand.

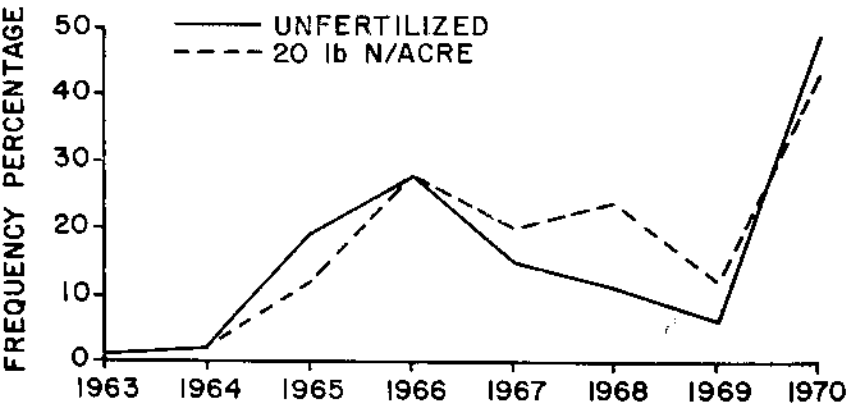

FIGURE 25.—Effects of years and N fertilization on sixweeks fescue.

Because there was no accumulation or retention of grazing effects across years, the frequency percentages for unfertilized and fertilized pastures in 1968–70 were averaged to determine the mean effects of repeated heavy grazing in different months (fig. 26). Heavy grazing at the time of seedling establishment in September through December was detrimental to sixweeks fescue. Through the remainder of the cool season, heavy grazing became less detrimental as the seedlings became more firmly established. After growth resumed in the spring, the plants were soon tall enough to be grasped and pulled by cattle, as shown by the thinning effect of heavy grazing in May and June. Finally, heavy grazing in July and August, when the seeds were shattering, was favorable if precipitation in the fall was sufficient for germination and establishment of a new stand.

Sixweeks fescue is so very undesirable that we must emphasize its control as one of the most important results of this experiment. When precipitation in September and October is sufficient to promote a lot of sixweeks fescue, cattle could be immediately concentrated on the worst areas to reduce the stands. Heavy grazing for a short time again the next May should further reduce the stand and prevent a big seed crop.

Control by concentrating cattle at the proper times to dislodge seedlings and pull up established plants, however, is less likely to be adopted as common practice than chemical and mechanical methods. Good control of sixweeks fescue has been obtained with simazine or atrazine at 1 lb/acre, which controlled

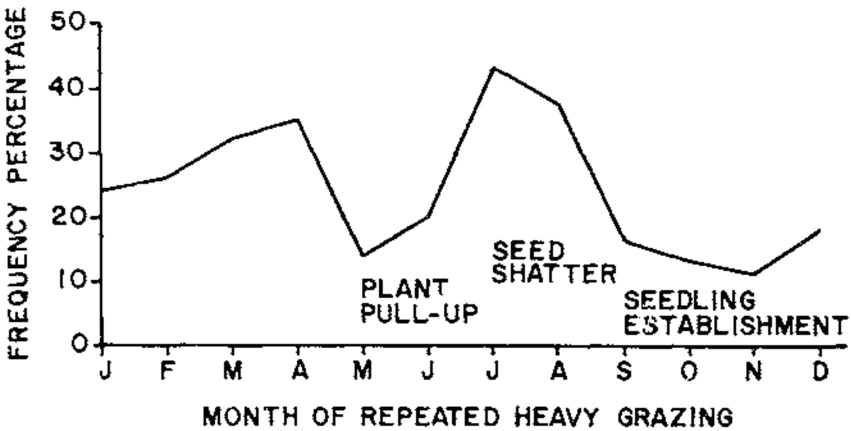

FIGURE 26.—Mean frequency of occurrence of sixweeks fescue averaged across the years 1968–70 to show the mean effects of repeated heavy grazing by individual months.

other annuals as well.[6] The characteristics of sixweeks fescue also suggest that harrows and other machines that scratch the soil should be evaluated for their effectiveness in pulling the plants. Such mechanical treatment probably would be most effective if applied in late May.

PRAIRIE PEPPERWEED

Yearly fluctuations in the stands of prairie pepperweed are shown in figure 27. N fertilization significantly increased stands in 1964 and 1967–70. The gain due to fertilization increased over the years, indicating accumulative effects. Stepwise regressions of frequency percentages on previous quarterly precipitation amounts were not useful in defining year effects for either unfertilized or fertilized pastures. Rather, variability among stands was too great to permit significant multiple correlation coefficients. In general, it appears that prairie pepperweed was favored by a dry summer, a wet fall, and a wet spring, which suggests classification as a winter annual. Prairie pepperweed responded as a winter annual by becoming established with above average precipitation in September, and as a summer annual in other years. It grew rapidly in May and June, if moisture was sufficient, and shattered seed in late June and July.

The months of repeated heavy grazing introduced significant differences among stands in 1968–70. However, these results should not be interpreted to mean that a grazing treatment must

[6] SLUIJS, D. H. VAN DER. RESPONSES OF SHORTGRA[illegible] RANGE AND BLUE GRAMA (BOUTELOUA GRACILIS (H.B.K.) LAG. EX STEUD.) PLANTS TO S-TRIAZINE HERBICIDES. 1972. [Unpublished Ph.D. Thesis. Colo. State Univ., Fort Collins.]

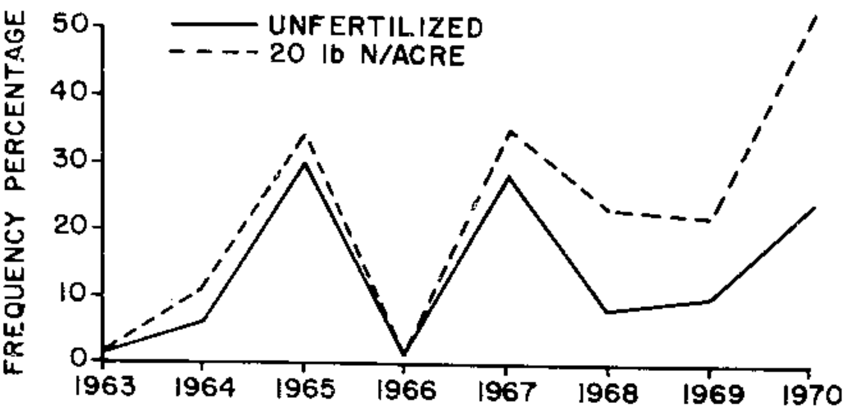

FIGURE 27.—Effects of years and N fertilization on prairie pepperweed.

be repeated 4 or 5 years to impose significant effects. Rather, the effects of grazing at different times in one year appeared the next year but did not accumulate across additional years.

Grazing in different months became effective only in a year when the stands were quite thick. Thus, grazing could have affected prairie pepperweed in 1965. If so, the effects would have been apparent in 1966, but the stands in 1966 were too thin to reveal such grazing effects. Also, the stands in 1966 were too thin to sustain new grazing effects that could be expressed in 1967.

Good stands were needed in two or more consecutive years, as in 1967 through 1970, to reveal effects of repeated heavy grazing in different months. The point is quite obvious with prairie pepperweed, but applies as well to most other annual species. Interactions between fertilization and the months of grazing were quite common among the annual species (table 4), because the stands on unfertilized pastures generally were too thin to be affected by grazing. For these reasons, frequency percentages were averaged across the 3 years 1968–70 to obtain mean effects of grazing in different months (fig. 28).

The months of repeated heavy grazing created large and significant differences in stands of prairie pepperweed only on fertilized pastures. Grazing in December through April was most favorable. Trampling in the winter probably helped plant the seed for better germination and establishment. Heavy grazing in

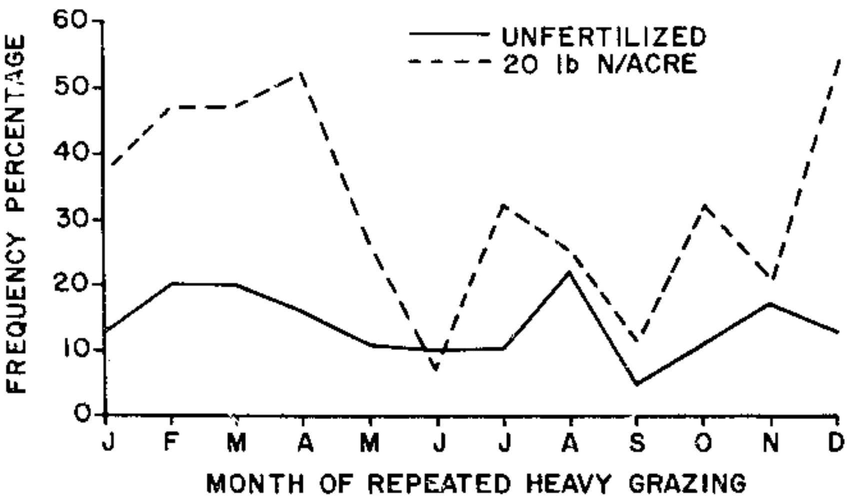

FIGURE 28.—Mean frequency of occurrence of prairie pepperweed averaged across the years 1968–70 to show the mean effects of repeated heavy grazing by individual months on unfertilized and fertilized pastures.

June was most detrimental, presumably because close grazing at that time was too late to permit regrowth and seed production for stands the next year.

Under heavy grazing, prairie pepperweed was cropped closely when it was green and tall enough to be taken by cattle; that is, in May and June. In fact, June is about the only time to effectively utilize prairie pepperweed. Heavy grazing at that time obtains best utilization of a thick stand and obtains a great measure of control by reducing seed production. Heavy grazing in June has not been harmful to the stands of blue grama, but its detrimental effects to some of the cool-season species, especially scarlet globemallow, and its effect in reducing herbage production make it necessary to use such grazing treatment sparingly and judiciously.

SMALLFLOWER CRYPTANTHA

Years, N fertilization, months of repeated heavy grazing, and fertilization-by-grazing interaction introduced significant differences in the frequency of occurrence of smallflower cryptantha. Year effects were most important (fig. 29). The stepwise regression of frequency percentages on quarterly precipitation amounts shows that smallflower cryptantha was favored by a dry summer and a wet winter.

$$\text{Smallflower cryptantha, unfertilized} = 42.1 - 4.23\,(S\text{–}1) + 6.53\,(F\text{–}2) - 2.49\,(S\text{–}2)$$
$$R = 0.944^*$$
$$\text{SEE} = 5 \text{ percent}$$

$$\text{Smallflower cryptantha, 20 lb N/acre annually} = 50.3 + 21.10\,(W\text{–}1) - 3.71\,(S\text{–}1) - 2.64\,(S\text{–}2)$$
$$R = 0.895$$
$$\text{SEE} = 8 \text{ percent}$$

This species is a summer annual that germinates in early spring and matures in early summer.

N fertilization increased stands each year from 1965 through 1970 (fig. 29). Months of repeated heavy grazing significantly affected stands in the last 3 years, but only on fertilized pastures, where grazing in April was most favorable and grazing in June most unfavorable (fig. 30). The negative effect of heavy grazing in either May or June was apparent in each of the last 5 years, and the favorable effect of heavy grazing in April was apparent in each of the last 6 years. Since those effects failed to produce significant differences before 1968, small residual effects may have been carried over from one year to the next.

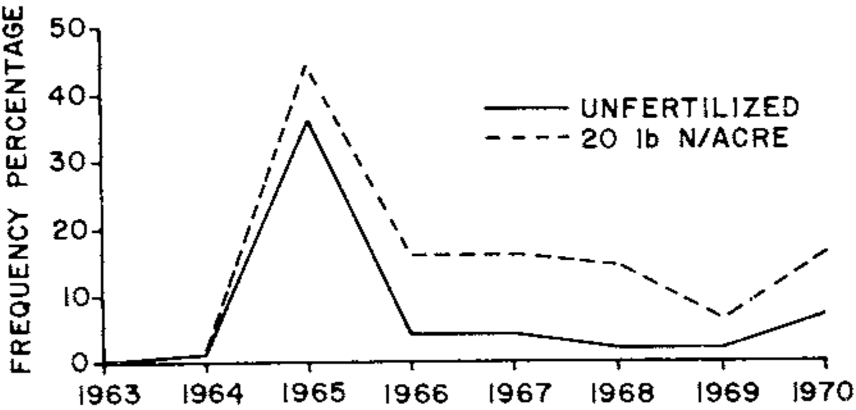

FIGURE 29.—Effects of years and N fertilization on smallflower cryptantha.

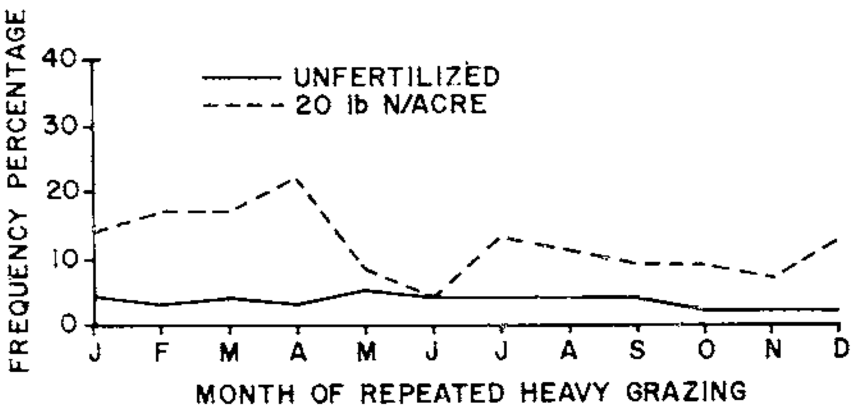

FIGURE 30.—Mean frequency of occurrence of smallflower cryptantha averaged across the years 1968–70 to show the mean effects of repeated heavy grazing by individual months on unfertilized and fertilized pastures.

Smallflower cryptantha becomes stiff and prickly when mature, but its small stature seems to preclude interference with grazing by cattle. N fertilization increased plant size as well as the number of plants, and thus increased the nuisance potential. Concentrating cattle for heavy grazing in May or June to control sixweeks fescue would also help control smallflower cryptantha by reducing seed production.

TANSYLEAF ASTER

Tansyleaf aster was affected significantly by year, N fertilization, and months of repeated heavy grazing. Year and N effects were very pronounced (fig. 31). Tansyleaf aster and prairie pepperweed were alone in responding to fertilization in the drought

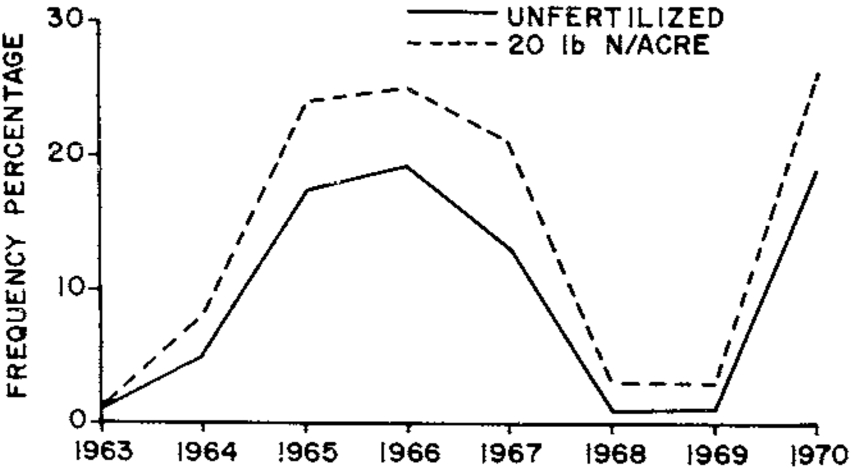

FIGURE 31.—Effects of years and N fertilization on tansyleaf aster.

year, 1964. Fluctuations among years were highly correlated with quarterly precipitation amounts, as follows:

$$\text{Tansyleaf aster, unfertilized} = 43.2 - 1.35\,(S\text{–}1) - 11.08\,(W\text{–}2) - 2.23\,(S\text{–}2)$$
$$R = 0.965^{**}$$
$$\text{SEE} = 3 \text{ percent}$$

$$\text{Tansyleaf aster, 20 lb N/acre annually} = 56.9 - 1.65\,(S\text{–}1) - 16.53\,(W\text{–}2) - 2.73\,(S\text{–}2)$$
$$R = 0.963^{**}$$
$$\text{SEE} = 4 \text{ percent}$$

Thus, tansyleaf aster was favored by a dry summer (*S*–2 and *S*–1) and a dry winter (*W*–2).

Additional steps in the stepwise regressions show positive effects of both spring and fall precipitation. Tansyleaf aster responded as a winter annual by germinating and establishing in the fall, and as a summer annual by germinating and establishing in the spring. Most of the winter annuals, such as prairie pepperweed and sixweeks fescue, are not obligate winter annuals. Adaptability for establishment either in fall or spring should favor the species and permit more consistent success among years. Tansyleaf aster was one of the most consistent annuals, with a few plants appearing even in the most unfavorable years.

Nevertheless, tansyleaf aster was affected significantly by the months of repeated heavy grazing only in 1968 and 1970. In 1968, the stands were thin (fig. 31), and differences due to grazing were quite unimportant. Therefore, mean frequency percentages in 1970 are shown in figure 32. Those results apply equally well to unfertilized and fertilized pastures. Grazing in September was most unfavorable and grazing in March most favorable to tansyleaf aster. The detrimental effect of heavy grazing in September, along with October, appeared as the primary effect in 1968. Even so it must be observed that tansyleaf aster was not readily susceptible to influence by grazing. It was seldom utilized by cattle even under heavy stocking rates.

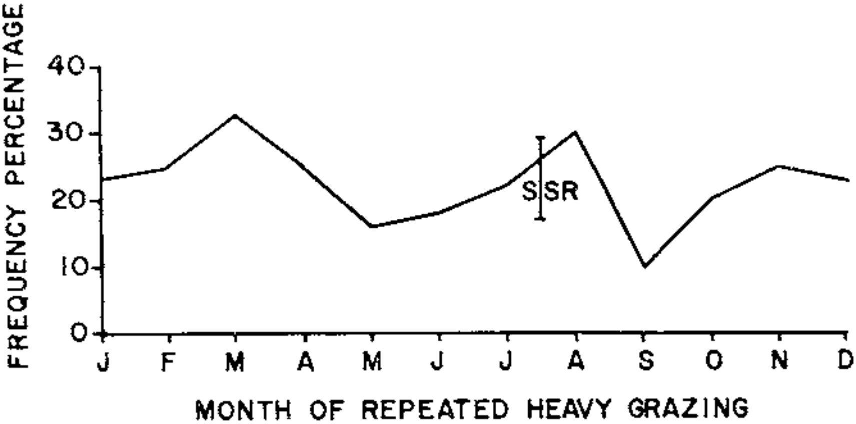

FIGURE 32.—Mean frequency of occurrence of tansyleaf aster in 1970 after 7 years of repeated heavy grazing in different months. Compare with figure 8.

OTHER ANNUAL SPECIES

Lambsquarter, second only to Russianthistle as an annual forage plant, fluctuated from 0 to 16 percent frequency among years, and increased with N fertilization when stands were sufficient to show the responses (fig. 33). Months of grazing were insignificant, except in 1969 when grazing the previous August was favorable and grazing in May was detrimental. Similar trends with grazing were apparent in other years, but grazing effects were essentially restricted to fertilized pastures. Frequency percentages never exceeded 4 percent on pastures fertilized and grazed in May, but with fertilization and grazing in August exceeded 15 percent in 1965, 1966, 1967, 1969, and 1970. When averaged across those years, grazing in November was even more favorable than grazing in August. The stepwise regression of mean frequency percentages on quarterly precipitation amounts shows that lambsquarter on unfertilized pastures was favored most by a dry summer and a dry fall. On fertilized

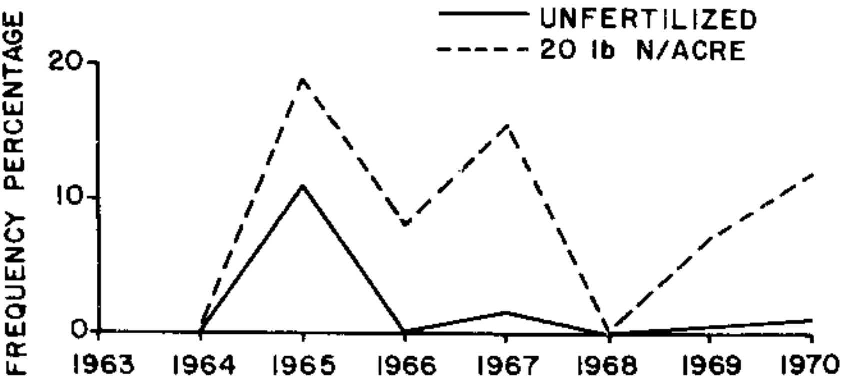

FIGURE 33.—Effects of years and N fertilization on lambsquarter.

pastures, it was favored most by a dry summer and a recent wet spring. Lambsquarter is a summer annual that generally shatters seed in late summer and fall.

Wooly indianwheat is a very small plant that responded to year differences (table 5) and remained unaffected by N fertilization. Significant differences due to months of grazing appeared in 1969 and 1970, when heavy grazing in September, October, or November was detrimental and heavy grazing in February through May was favorable. The stepwise regression shows that this species was favored by a dry summer followed by a dry winter and finally a wet summer for good plant growth and buildup of seed. In fact, this was the only annual showing a positive relation to previous summer precipitation. Frequencies fluctuated from 1 to 15 percent among years.

Little goosefoot fluctuated among years from a mean frequency of 0 to 12 percent in a manner very similar to slimleaf goosefoot and lambsquarter. All three of these species were favored by previous dry summers and a recent wet spring. All responded to N fertilization, and all were affected significantly by the months of repeated heavy grazing in 1969. For little goosefoot, grazing in May never permitted mean frequencies greater than 4 percent, whereas grazing in August permitted frequencies above the overall mean in 1965, 1967, 1969, and 1970. Consequently, all three of the *Chenopodium* species responded in common ways.

Ridgeseed euphorbia fluctuated from a mean frequency of 0 to 11 percent among years, but was not affected significantly by either N fertilization or the months of repeated heavy grazing. Significant correlation with quarterly precipitation amounts shows that this species was favored by a dry fall, a dry winter, and a wet spring. This relation to precipitation suggests that ridgeseed euphorbia is a summer annual that germinates relatively late in spring, when soil temperatures are quite warm.

Gilia fluctuated from a mean frequency of 1 to 7 percent among years, but was not affected significantly by either N fertilization or the months of repeated heavy grazing. Highly significant correlation with quarterly precipitation amounts shows that Gilia was favored by dry summers and a recent wet winter. This relation to precipitation suggests that Gilia is a summer annual that germinates in late winter and early spring when soil temperatures are still quite cool.

Redowski's stickseed fluctuated from a mean frequency of 0 to 8 percent among years. It was significantly increased by N fertilization in 1967 through 1970, but the means across those years were just 2 and 5 percent for unfertilized and fertilized pastures, respectively. The months of repeated heavy grazing did not cause significant variation in stands; however, grazing in May generally was detrimental to stands. Redowski's stickseed was favored by a wet spring followed by a dry summer and a wet fall. It was observed to be a winter annual, germinating in the fall if precipitation were sufficient. The previous wet spring apparently favored seed production, which is very small in most years. The mature fruits (burrs) appearing in late June and July are very prickly. Thick stands probably would annoy cattle and interfere with grass utilization.

Plant Community Relations

Plant community relations were analyzed by correlating pairs of species and by stepwise regression in which each species in turn was designated as the dependent variable and all other species as independent.

The correlation matrix given in table 14 represents frequency data obtained in all 8 years. The species are arranged in sets that include most of the significant positive correlations. Annual species in set 5 show the greatest association. Between sets the correlations are generally less than 0.2. Larger positive values are found between sets 1 and 2. Otherwise, the correlations between sets are mostly negative, suggesting competition between sets. The main point of emphasis, however, must be that associations between species were very weak. Each species was quite individualistic in the way it responded to weather, grazing, and N fertilization.

Simple correlation matrices were computed for each year of sampling. The relations changed a little from year to year, but remained weak throughout. A factor analysis, also, was employed, but the weak relations were swamped by variability.

The stepwise regression goes beyond the correlation matrix by revealing the total dependence of a species on the rest of the community. We expected that a few, perhaps four or five species, would appear statistically dominant as independent variables that largely controlled the stands of all other species. If so, the key species would provide a substantial framework for range condition classification.

The 27 species considered as dependent variables are listed in table 15 in decreasing order from left to right according to the amount of variability (R^2) accounted for by all other species. Surprisingly, blue grama (BOGR2) among the perennial species appeared most dependent on other species, which accounted for 48 percent of the variability in blue grama stands. Because blue grama is obviously dominant, we expected it to be more independent than other species. Among the annual species, slimleaf goosefoot (CHLE4) was most dependent and Russianthistle (SAKAT) least dependent. The perennial species were more dependent on other perennials, and the annuals were surprisingly more dependent on other annuals. This statistical dependence is certainly not very profound. In fact, the term dependence incorrectly implies a plant to plant cause and effect relation.

The causes for changes in density must be the factors of weather and treatments. Although at any time or place some species may increase while others decrease, the weak statistical relationship among species shows that these responses divide the species in a great variety of ways—that a change by one species or a group of species does not cause an obligate increase or decrease by another species. Our appreciation of this independence and individualism of species was initially complicated by the conception of herbage production, which obviously requires the theory of obligate responses and compensatory yield. If some species increase in production, others must decrease because the environment imposes a limit on total herbage growth. Also, if some species decrease, others will compensate within certain limits by increasing their production. This theory appears incorrect in terms of plant frequency or density.

Considered as independent variables, the species are listed in table 15 from top to bottom in decreasing order according to their total apparent influence on other species. Unfortunately, no key species accounted for the responses of others. The group of just 27 species can theoretically change in an almost infinite number of ways, and appears to have done just that. Conse-

TABLE 14.—*Correlation*[1] *matrix among 27 species arranged in sets according to associated responses*

Set and species	1						2			3		4	
	SPCO	GACO5	LYJU	AGSM	EREF	PSTE3	ARLO3	STCO4	SPCR	BOGR2	CAHE5	OPPO	CAFI
1.													
SPCO	1.0	0.45	0.34	0.32				0.25		..	..	−0.42	−0.23
GACO5		1.0	.42	.20		0.26	..	..	..	0.22	..	−.25	..
LYJU			1.0	.31	0.20		..			..	0.29	−.30	..
AGSM				1.0	.20		0.20	.29		..	..	−.23	..
EREF					1.0	.		.32		−.38	..	..	..
PSTE3						1.0				..	..	..	..
2.													
ARLO3							1.0	.39	0.30	..	−.23	..	..
STCO4								1.0	.22	−.24	..	..	..
SPCR									1.0	..	−.26	..	..
3.													
BOGR2										1.0	.26	..	−.20
CAHE5											1.0	..	..
4.													
OPPO												1.0	.23
CAFI													1.0
5.													
CRMI5													
MATA2													
LEDE													
CHLE4													
LARE													
CHIN2													
OECO2													
ASTRA													
GILA3													
EUGL3													
SAKAT													
CHAL7													
FEOC2													
PLPS													

Set and species	5													
	CRMI5	MATA2	LEDE	CHLE4	LARE	CHIN2	OECO2	ASTRA	GILA3	EUGL3	SAKAT	CHAL7	FEOC2	PLPS
1.														
SPCO	..	..	0.27		..	..	..	..	..	..	..	..	0.20	..
GACO5	..	−0.21			..	..		..	..		..	..	..	..
LYJU	..	..	..		..	..	0.26	..	..	..		..	..	..
AGSM	..	..			..	..	.21		..	..	..	..	..	..
EREF	..	..			..	..	..	−0.23	..		..	..		
PSTE3		..			..	..	..	..	..	..	..	..	..	..
2.														
ARLO3	−0.28	..		−0.32	..	..	..	..	..	..	−0.28	−0.33	−.20	..
STCO4		..		..	..	..	..	..	..	..	..	..	..	..
SPCR				..	..	..	..		..		..	−.21		..
3.														
BOGR2	−.37	−.27	..	−.27	..	−0.24	..	−.20	−0.26	−0.32	..	..	..	..
CAHE5	..	..	..	..	..	..	..	..	..	..	..	..	..	..
4.														
OPPO	..	..	..		−0.28	..	..	..	..	..	..	−.25	−.27	..
CAFI	..	..	..	..	..	.	..	..	..	..	..	..	..	..
5.														
CRMI5	1.0	.55	.54	.50	.41	.38	.46	.57	.52	.43	.36	.24	.27	..
MATA2		1.0	.48	.38	.37	.23	..	.30	.26	..	.41		.40	0.47
LEDE			1.0	.64	.56	.45	.33	.23	.24	..	.34	..	.35	.35
CHLE4				1.0	.39	.64	.29	.26	.24	.26	.45	.36	.32	..
LARE					1.0	.43	.25	.30	..	..	.28	.25	.33	.25
CHIN2						1.0	.27	.23	..	.27	.25	.27	.21	..
OECO2							1.0	.28	.33	.29	..		..	..
ASTRA								1.0	.44	.38	..	.33	..	..
GILA3									1.0	.38	..	..	..	.27
EUGL3										1.0	..	..	..	..
SAKAT											1.0	.37	.27	..
CHAL7												1.0	..	..
FEOC2													1.0	.35
PLPS														1.0

[1] Correlation coefficients less than 0.20 were omitted; although with $n-2 = 766$ degrees of freedom, an r of 0.10 is significant at 1 percent.

TABLE 15.—*Percentage of variability (R^2) in frequency of occurrence of the dependent variable accounted for by the independent variables in stepwise regression where all variables are plant species. Table includes individual values of 2 percent or more*

Independent variables [1]	Dependent variables													
	Perennial species													
	BOGR2	OPPO	EREF	SPCO	ARLO3	LYJU	GACO5	STCO4	OECO2	CAHE5	AGSM	CAFI	SPCR	PSTE3
SPCO	--	18*	--	--	--	--	20	2		2	10	3*	--	--
GACO5	--	--	--	20	--	18	--	--	--	--	--	--	--	7
LYJU	6	2*	6	--	--	--	8	2*	9	9	6	--	--	--
EREF	14*	2	--	--	--	3	--	7	--	--	--	--	2	--
OPPO	--	--	2	10*	--	--	--	--	--	--	--	5	2*	5
BOGR2	--	--	15*	--	2*	2	--	4*	--	4	--	2*	--	--
STCO4	5*	--	3	2	15	2*	--	--	--	--	5	--	--	--
ARLO3	--	--	--	--	--	--	--	15	--	2*	--	--	9	--
ASTRA	--	--	10*	--	--	--	--	--	--	--	--	--	--	--
AGSM	--	2*	--	4	--	4	--	3	3	--	--	--	--	--
SPCR	--	--	--	--	4	--	--	--	--	6*	--	--	--	--
CAHE5	--	--	--	--	--	6	--	--	--	--	--	--	4*	--
PSTE3	--	3	--	--	--	--	3	2*	--	--	--	2	--	--
OECO2	--	--	--	--	--	3	--	--	--	--	--	--	--	--
CAFI	3*	--	--	--	--	--	--	--	--	--	--	--	--	--
CRMI5	15	--	--	--	--	--	--	--	21	--	--	--	--	--
CHLE4	3*	--	--	--	3*	--	--	--	--	--	--	--	--	--
MATA2	2*	4	4*	--	--	--	4*	--	--	--	--	--	--	--
LEDE	--	--	--	4	--	--	--	--	--	--	--	--	--	--
PLPS	--	--	--	--	2	--	--	--	--	2*	--	--	--	3*
CHIN2	--	--	--	--	--	--	--	--	--	--	--	--	--	--
SAKAT	--	--	--	--	10*	--	--	--	--	--	--	2*	--	--
FEOC2	--	4*	2	--	2*	--	--	--	--	--	4*	5	--	--
CHAL7	--	6*	--	--	2*	--	--	--	--	--	--	--	--	--
LARE	--	2*	--	--	--	--	--	--	--	--	--	--	--	--
GILA3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
EUGL3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	48	43	42	40	40	38	35	35	33	25	25	19	17	15

Independent variables [1]	Dependent variables												
	Annual species												
	ASTRA	CHLE4	LEDE	MATA2	CHIN2	PLPS	LARE	GILA3	FEOC2	CRMI5	CHAL7	EUGL3	SAKAT
SPCO	--	--	--	--	--	--	--	--	--	--	--	--	--
GACO5	--	--	--	4*	--	--	--	--	--	--	--	--	--
LYJU	--	--	--	--	--	--	--	--	--	--	--	--	--
EREF	4*	--	--	--	--	--	--	--	4	--	--	--	--
OPPO	--	--	--	--	--	--	4*	--	3*	--	4*	--	--
BOGR2	--	2*	--	--	--	--	--	--	--	--	--	3*	--
STCO4	--	--	--	--	--	--	--	--	--	--	--	--	--
ARLO3	--	2*	--	--	--	--	--	--	--	--	--	--	--
ASTRA	--	--	--	--	--	--	4	--	--	4	8	--	--
AGSM	--	--	--	--	--	--	--	2	5*	--	--	--	--
SPCR	--	--	--	--	--	--	--	--	--	--	3*	--	--
CAHE5	--	--	--	--	--	--	--	--	--	--	--	--	--
PSTE3	--	--	--	--	--	--	--	--	--	--	--	--	--
OECO2	--	--	--	--	--	--	--	--	--	3	--	--	--
CAFI	--	--	--	--	--	--	--	--	2	--	--	--	--
CRMI5	7	--	3	31	--	3*	--	27	14	--	--	18	--
CHLE4	--	--	41	--	41	4*	--	--	--	--	--	--	2
MATA2	--	--	--	--	--	22	--	--	--	15	--	3*	11
LEDE	--	15	--	--	--	3	32	2*	--	--	--	--	--
PLPS	--	--	12	14	--	--	--	5	5	--	2	--	--
CHIN2	--	41	--	--	--	--	2	--	--	--	--	--	--
SAKAT	--	5	--	--	--	--	--	2*	--	--	14	--	--
FEOC2	--	--	--	--	--	3	--	--	--	2	--	--	--
CHAL7	2	--	--	--	--	--	--	--	--	--	--	--	5
LARE	--	--	7	--	4	--	--	--	--	--	--	--	--
GILA3	--	--	--	--	--	7	--	--	--	2	--	--	--
EUGL3	--	--	--	--	--	--	--	--	--	6	--	--	--
Total	13	65	63	49	45	42	42	38	33	32	31	24	18

[1] Independent variables entered into the stepwise regression with positive or negative regression coefficients. Those marked by asterisk entered as negative coefficients; all others, as positive coefficients.

quently, the most objective definition of the "community" is nothing more than the list of species. Individual stands can be sampled and described in great detail, and changes in frequency of occurrence of individual species in any given year can be tentatively defined as a function of botanical composition in the previous year, the amount and seasonal distribution of precipitation during the year, and the kind of grazing and fertilizer treatments imposed. The possibilities for a mathematical model of changes in botanical composition are under consideration.

Animal Responses

YEAR EFFECTS

Stocking rates, year effects, and animal gains fluctuated greatly among years. These year effects were largely associated with the amounts of precipitation received in the warm-season months April through September, inclusive. Precipitation in the warm season accounted for about 82 percent of the average annual precipitation and affected stocking rates and animal gains in ways related to the time of grazing. This evaluation was slightly complicated by the necessity for entering the precipitation in the 6 warm-season months that preceded the time of grazing. For example, stocking rates and animal gains in January through April were considered in relation to precipitation in April through September of the previous year because grazing depended on herbage growth in the previous year. Grazing in May was considered in relation to precipitation in April of that year plus that in May through September of the previous year, and so on for other months of grazing.

Animal daily gains were not consistently correlated with warm-season precipitation. However, there was an important interaction that deserves consideration. With grazing in June and July, the daily gains were positively correlated ($r = 0.82$, $n-2 = 10$) with warm-season precipitation. Conversely, daily gains were negatively correlated ($r = -0.44$, $N-2 = 16$) with warm-season precipitation with grazing in October, November, and December. In June and July, forage quality was best when the herbage was green and growing; that is, with frequent precipitation. However, high herbage production, as obtained with above-average precipitation through the warm season, resulted in coarse herbage of relatively low quality in the fall and winter. In fact, crude-protein concentrations in cured herbage varied from about 12 percent following a dry summer to about 4 percent following a wet summer.

The calculated amounts of net energy harvested by the animals were positively and significantly correlated (average $r = 0.89$, $n-2 = 4$ years) with warm-season precipitation, but this relation varied considerably depending on the time of grazing. The weakest relation ($r = 0.57$) was obtained with grazing in July, and the strongest relation ($r = 0.97$) was obtained with grazing in September or October. Total herbage production, and, consequently, the amount of net energy harvested, increased with an increase in warm-season precipitation. That relation was best measured by animal responses with grazing at the very end of the warm season; that is, in September or October. Later in the winter and following spring, animal responses became more remotely related to the previous warm-season precipitation. This might be understood as accumulative effects of wind, temperature, and cool-season precipitation on the supply and quality of forage and on animal responses.

Stocking rates, in number of animal-unit days of grazing per acre, were positively, and for most months of grazing highly significantly, correlated with warm-season precipitation (fig. 34). The corresponding linear regression coefficients were equal for grazing in the cool-season months, October through April, and diverged from this base period for grazing in warm-season months. Herbage growth was insufficient for any grazing when warm-season precipitation was less than about 4 or 5 inches, as indicated by the interception of regression lines on the base line in figure 34.

The slopes of the regression lines show that additional increments of warm-season precipitation gave the smallest increments of additional grazing in June and the largest increments of grazing in September. The figure was simplified by omitting July, which was nearly identical to the line for June, and August which was nearly identical to the line for October to April. Grazing in May, June, or July presumably reduced herbage production and stocking rates.

In the 34 years 1939–72, inclusive, the median warm-season precipitation was 10.46 inches (table 16). Fifty percent of the years fell within the relatively narrow limits of 7.71 to 12.46 inches of warm-season precipitation. Precipitation amounted to less than 5 inches in 4 years or 12 percent of the 34 years. One should subtract about nine animal-unit days of grazing per acre to translate the results of heavy grazing to a moderate stocking rate. Thus, moderate grazing would not be justified with less

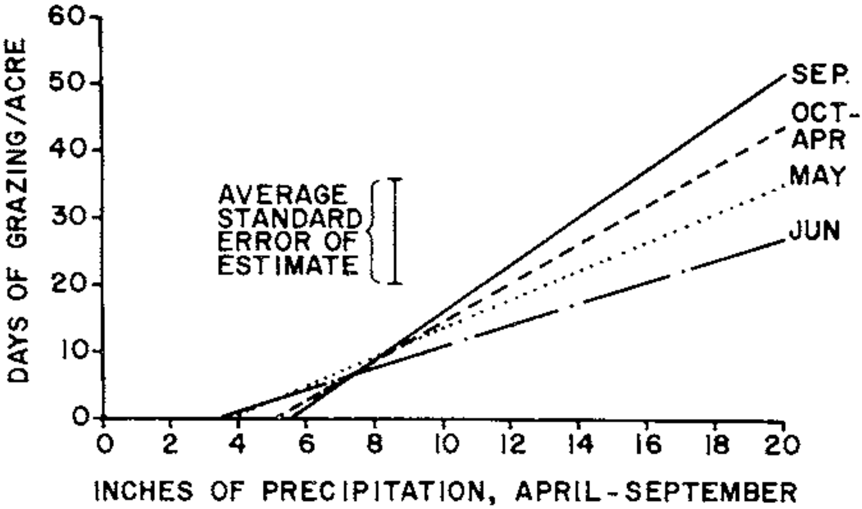

FIGURE 34.—Effects of the amount of precipitation received in the warm season, April to September, on the number of animal-unit days of grazing per acre when grazing was restricted to an individual month.

than about 8 inches of precipitation in the warm season, unless there was a considerable carryover of old herbage from a previous year.

SEASON-OF-GRAZING EFFECTS

Mean daily gains and gains per acre plotted by months of grazing appear very similar because the yearlings gained weight in May through September and lost weight in cool-season months (figs. 35 and 36). Compared with moderate stocking for continuous yearlong grazing (unpublished data), this repeated monthly heavy grazing reduced animal daily gains in every month, averaging 0.86 lb/day less. The seasonal trends in liveweight gains and losses reflect composite changes in forage digestibility and intake. Animal gains, and presumably forage quality, attained maximum in July and decreased rapidly through the late summer and fall.

The stocking rate in number of animal-unit days of grazing per acre provides an index of herbage production. By this index, production was greatest with grazing in August or September and least with grazing in June or July (fig. 37). Even though forage quality decreased rapidly after August, the stocking rate held up very well throughout the cool-season months, then dropped sharply through May and June. Grazing in May, June, and July provided fewer days of grazing for two reasons: Total herbage available was least and energy intake per animal-unit day of grazing was greatest with grazing at that time.

It appears that heavy grazing in June was most severe in reducing herbage production, because in other studies (unpublished data) forage intake averaged over several years has remained near maximum through June, July, and August. Stocking rates for cool-season grazing can be a little larger than those for

TABLE 16.—*Median and quartile limits of precipitation received in the warm season, April to September, 1939–72*

Year	Precipitation	Quartile limits	Quartile ranges
1939	3.45	3.45	
1954	3.60		
1964	3.70		
1960	4.80		
1948	6.17		4.26
1944	6.58		
1970	6.60		
1943	6.83		
1942	7.71	7.71	
1956	8.07		
1946	8.42		
1959	8.80		
1971	8.83		2.75
1958	9.93		
1951	10.02		
1966	10.15		
1955	10.42	10.46	
1945	10.50		
1953	10.51		
1950	10.65		
1968	10.68		2.00
1949	10.86		
1963	11.59		
1947	11.85		
1972	12.37		
1952	12.46	12.46	
1940	12.48		
1962	12.68		
1969	12.84		
1961	13.28		7.81
1965	13.64		
1957	13.98		
1941	17.79		
1967	20.27	20.27	

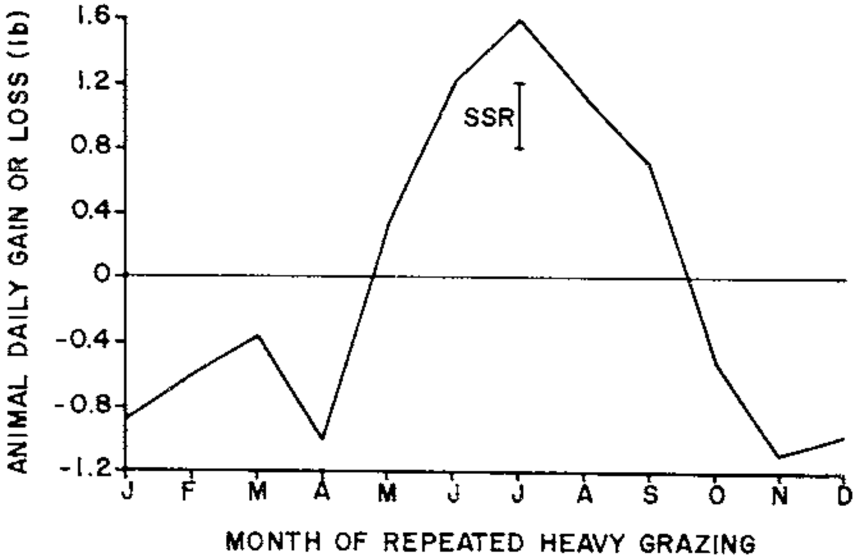

FIGURE 35.—Seasonal trends in liveweight daily gain by yearling Hereford heifers.

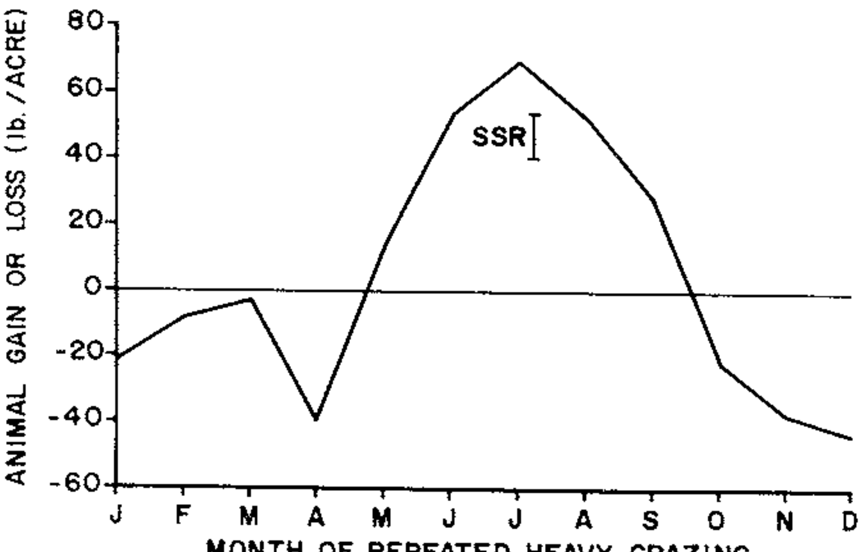

FIGURE 36.—Seasonal trends in liveweight gain per acre by yearling Hereford heifers.

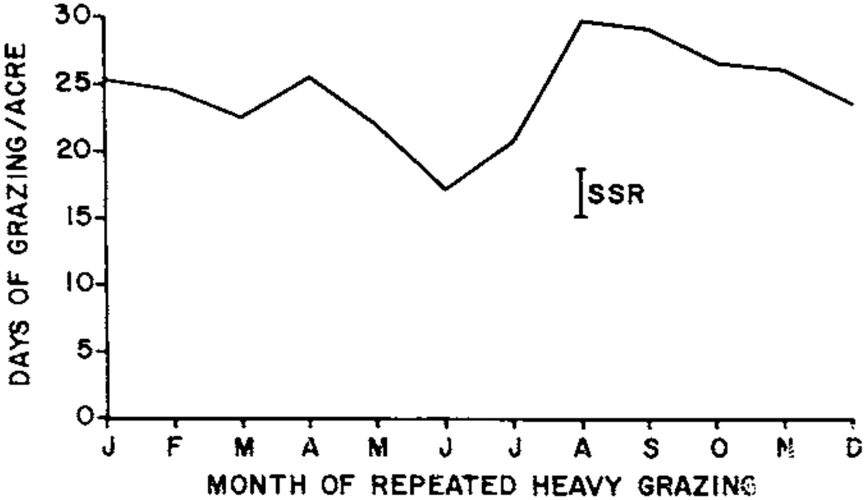

FIGURE 37.—Seasonal trends in stocking rates (animal-unit days of grazing per acre) for the Plains Upland Site of shortgrass range stocked heavily.

warm-season grazing because the cool-season grazing permits maximum herbage production and low forage intake. Herbage decay and disappearance is not of great consequence until spring.

The amounts of energy harvested, as calculated from National Research Council requirements for maintenance and gain, provide another index of herbage production (fig. 38). As with stocking rates, the greatest amount of energy was obtained with grazing in August; however, unlike stocking rates, the amount of energy harvested dropped sharply after September, remained at about half of the August maximum through the cool-season months, and increased through May, June, and July.

Each of these indexes of forage quality and quantity is relevant to grazing management. To obtain good pasture production, close grazing should be avoided in May, June, and July. Otherwise, the grazing plan can be quite free from vegetative requirements and limitations, except as discussed for individual species. Decisions relative to cattle management should coincide with the class of cattle. Liveweight gain is essential for young growing cattle. Thus, a unique operation involving the purchase of yearling cattle in late June for grazing in July, August, and perhaps into September would obtain essentially maximum production per animal as well as per acre of rangeland. The maximization of profits would require the additional consideration of cattle market prices and overhead costs that accompany all livestock operations. In the conventional year-round operation, the

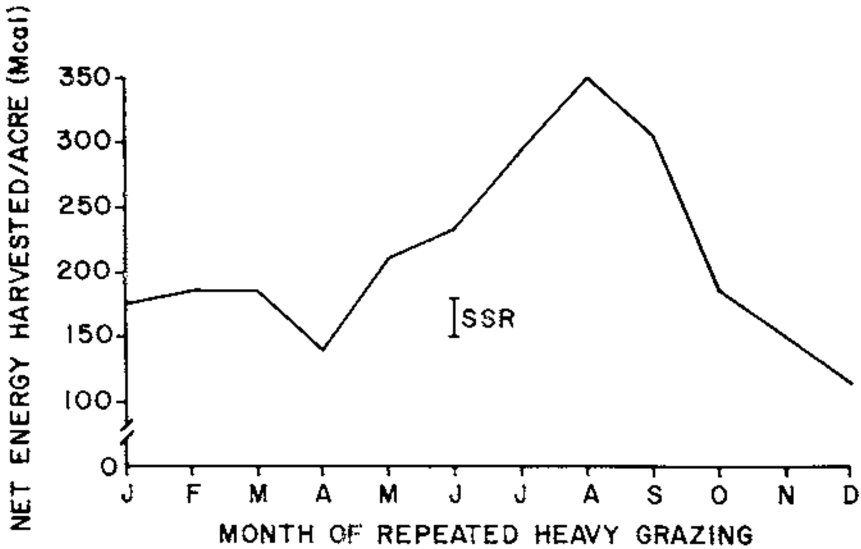

FIGURE 38.—Seasonal trends in the amount of net energy harvested per acre by yearling Hereford heifers.

indexes of forage quality and quantity suggest the need for feed supplementation for growing animals from October through April. Supplemental feed could be terminated in May, depending on plant growth and the time of adequate new herbage.

SOIL FERTILITY EFFECTS

Fertilizer applications increased animal daily gains, or reduced daily losses, in 49 of the 60 months of grazing. This increase amounted to an overall 0.36 lb/day, which was highly significant. Differences in the amount of increase due to fertilizer were not significantly different among years or among the months of grazing. However, heavy grazing might have masked cattle responses to seasonal differences in forage quality.

Although N fertilizer increased animal daily gains, animal gains per acre were actually less on fertilized than on unfertilized pastures in April and December (fig. 39). Increases in animal gain per acre due to fertilization were greatest in the months June through November.

N fertilizer increased the stocking rates (animal-unit days of grazing per acre) in every month (fig. 40). The smallest increases in stocking rates were obtained in May, June, and July, and the largest increases were obtained in August and September. Thus, grazing in August and September permitted a maximum plant response to fertilizer and harvested the forage when its quality was good enough to maintain high animal daily gains. Conversely, grazing in May, June, and July appears to have seriously reduced herbage response to fertilizer. The difference appears largely a matter of herbage quantity, because the increases in daily gains with fertilizer were not significantly dif-

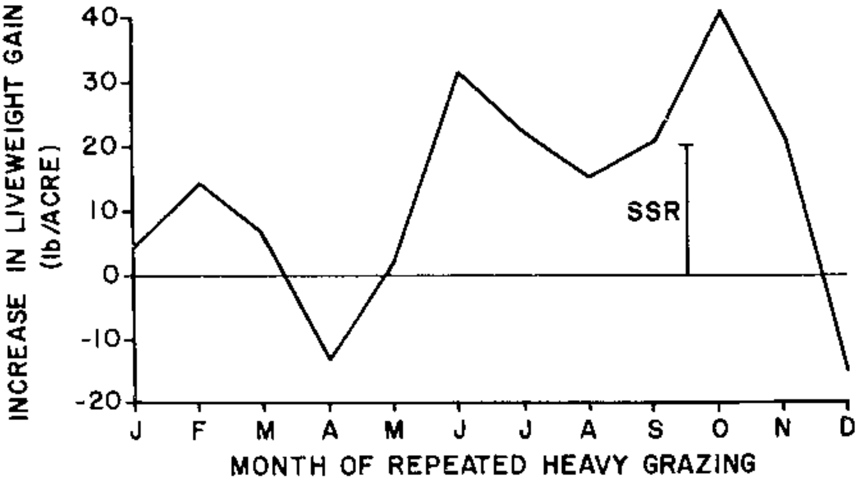

FIGURE 39.—Increases in liveweight gain per acre obtained by applying N fertilizer at a rate of 20 lb N/acre.

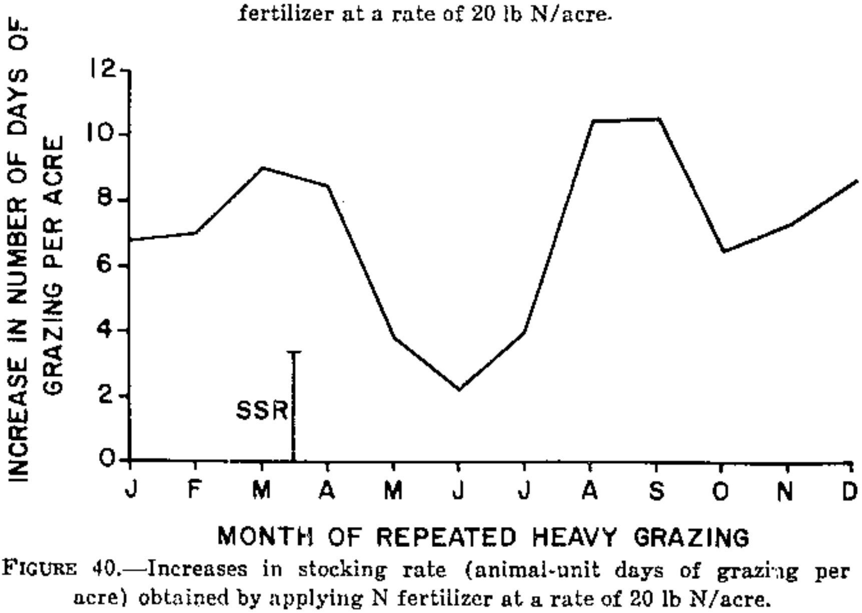

FIGURE 40.—Increases in stocking rate (animal-unit days of grazing per acre) obtained by applying N fertilizer at a rate of 20 lb N/acre.

ferent among the months of grazing. The point is greatly important in terms of maximizing returns from N fertilizer on rangelands. Contrary to the popular conception of earlier grazing on rangeland with N fertilizer, the maximization of returns will require attention to the possibilities of reducing herbage response to fertilizer by allowing grazing during the early stages of plant growth.

Returns from N fertilizer may be maximized by combining the best increases in stocking rates with high animal daily gains. Stocking fertilized pastures at a moderate rate for continuous grazing through June, July, August, and September should permit a near-maximum plant response and increase in liveweight gains by young marketable animals. Grazing in those months increased the stocking rate by 6.8 animal-unit days per acre and animal gains by an average of 0.34 lb/day and 22 lb/acre. The longtime average stocking rate for moderate grazing on unfertilized pastures provided 6.9 animal-unit days of grazing per acre. Fertilizing the shortgrass plains specifically for grazing in June through September by young marketable animals appears quite profitable. For example, each additional pound of gain, selling at more than 40 cents in 1972, costs about 15 cents for the purchase and application of N fertilizer. The main question remaining is whether the increases by fertilization can be obtained with moderate as well as with heavy grazing. Because moderate grazing requires that 300 pounds of herbage per acre be left ungrazed (*3*), it seems likely that most of the increase due to N fertilization might be obtained at moderate stocking rates. Field trials are needed to test this hypothesis and obtain true cost-comparison data.

Because net liveweight gains are not necessary for mature cows in a breeding herd, the maximization of returns due to N fertilizer for breeding animals should be determined by increases in stocking rates and increases in the amounts of net energy harvested. Maximum increases in stocking rates were obtained in August and September, and maximum increases in the amounts of net energy harvested were obtained in September and October (fig. 41). Consequently, fertilized pastures intended for the breeding herd might be grazed in August through November to maximize returns from N fertilizer. This period of use provided an average increase in stocking rate of 8.7 animal-unit days per acre and an increase of 126 megacalories of net energy per acre. Such an increase in stocking rate, costing about 34 cents per animal-unit day or $10.34 per animal-unit month, would surely be unprofitable unless calf daily gains also increased

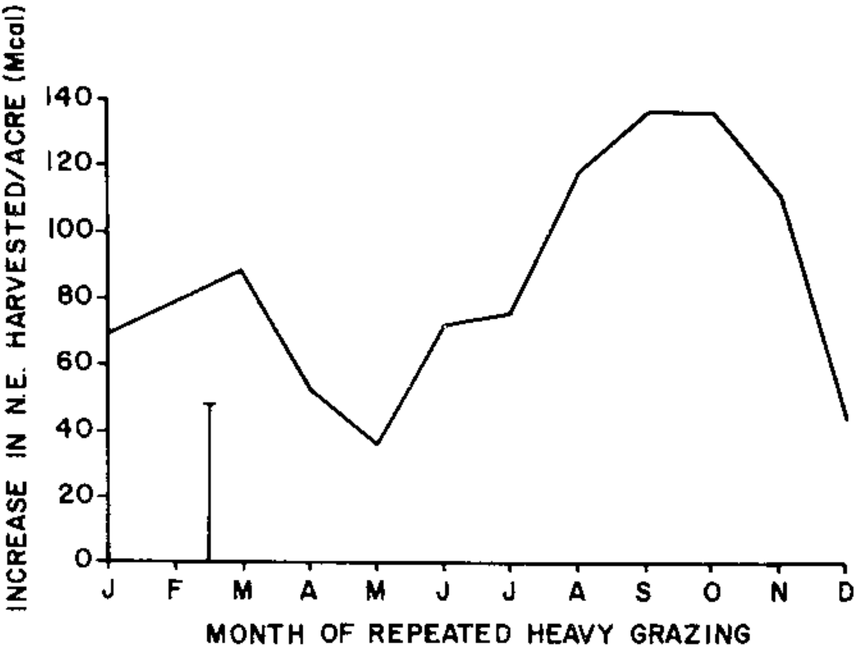

FIGURE 41.—Increases in the amount of net energy harvested per acre obtained by applying N fertilizer at a rate of 20 lb N/acre.

considerably. Field trials are also needed to evaluate cow and calf responses to N fertilization with grazing in August through November.

SUMMARY AND CONCLUSIONS

Weather and Grazing Effects on Individual Species

Although each plant species exhibited individual responses to weather conditions, the stepwise regression of frequency percentages on quarterly precipitation amounts revealed response patterns that permit the grouping of species. Blue grama, red threeawn, and plains pricklypear are listed as warm-season perennials because they exhibited positive responses to precipitation in the summer quarter (table 17). They have previously been classed as warm-season perennials by phenological observations. Because growth by the two warm-season grasses often continues in September, they responded positively also to precipitation in the fall quarter.

Cool-season perennials were favored by above-average precipitation in the spring quarters, and most of them also responded favorably to precipitation in the fall. Differences among them in the kind of reaction to quarterly precipitation amounts reflect differences in the biological mechanisms involved in the increase in stand density and frequency. The forbs may increase by establishing new plants from seed; whereas the grasses may increase by vegetative expansion as well as by seed.

The annual species are listed in table 17 as either summer annuals or winter annuals according to their responses to quarterly precipitation amounts and phenological observations. All of them, except wooly indianwheat, responded negatively to precipitation in the summer quarter. Those listed as summer annuals are quite diverse in showing positive responses to quarterly precipitation amounts. Russianthistle and smallflower cryptantha were positively associated with winter precipitation because they germin-

TABLE 17.—*Summary of positive and negative effects of quarterly precipitation amounts on the frequency of occurrence of individual plant species*

Groups and species	Precipitation quarters[1]			
	Summer	Fall	Winter	Spring
Warm-season perennials:				
Blue grama	+	+		
Red threeawn	+	+	−	
Plains pricklypear	+	−		−
Cool-season perennials:				
Scarlet globemallow	−	+		+
Needleandthread	−	+		+
Western wheatgrass	−	+		+
Sun sedge		+	−	+
Sand dropseed		−	+	+
Scarlet gaura			−	+
Summer annuals:				
Russianthistle	−		+	
Smallflower cryptantha	−		+	
Slimleaf goosefoot	−			+
Wooly indianwheat	+		−	
Winter annuals:				
Sixweeks fescue	−	+	−	+
Tansyleaf aster	−	+	−	+
Prairie pepperweed	−	+		+
Redowski's stickseed	−	+		+

[1] For this analysis, the summer quarter includes June, July, and August; fall includes September, October, and November; winter includes December, January, and February; and spring includes March, April, and May.

ated very early in the spring if moisture was sufficient. Slimleaf goosefoot germinated a bit later and responded positively to precipitation in the spring quarter. Wooly indianwheat appeared to germinate still later and responded positively only to summer precipitation.

The winter annuals were consistent in responding positively to both fall and spring precipitation. They characteristically germinated in the fall when conditions were favorable; otherwise, they germinated the next spring.

The species not included in table 17 were not greatly influenced by precipitation in any quarter.

N fertilization was primarily deleterious to the stands of perennial species and beneficial to the annuals (table 18). It appears that environmental modifications, as by soil nutrient amendment, are most likely to favor stand increases by a few subdominant or rare species than by dominant species in native vegetation. The reason would be that dominant species are most completely adapted to the natural environmental conditions, and that major changes in the environment might provide otherwise deficient elements for subdominant or rare species. In any event, such modifications should change botanical composition by favoring some species more than others.

Although induced changes in botanical composition are not necessarily undesirable from a husbandry point of view, they can be considered as counterproductive from an ecological point of view. Considered from the husbandry point of view, N applications were desirable in terms of the decreases in red threeawn and plains pricklypear, increases in Russianthistle, and increases in animal production. The fertilizer was undesirable in terms of the decreases of blue grama and sand dropseed and increases by many undesirable annuals. A more critical consideration involves both the ecological and husbandry points of view; that is, N fertilization threatens potential disaster to the dominant species, blue grama. Consequently, N should not be applied after a dry summer.

Repeated heavy grazing by individual months was included in this experiment to define the opportunities for influencing botanical composition by grazing. The study of plant responses to grazing should provide practical benefits as well as technical knowledge. Repeated heavy grazing failed to produce consistent effects from year to year. Rather, most of the significant effects of repeated heavy grazing were derived from isolated events—interactions between weather and grazing. In any single year, differences in botanical composition could be described as a summation of the effects of previous isolated events going back perhaps for many years. The results do provide some guides relative to effects of heavy grazing on individual species, but in nearly every case the combination of effects for all species reveal mixed blessings.

In summarizing the most important effects, we find that repeated heavy grazing in April through September created about three times as many key responses as repeated heavy grazing

TABLE 18.—*Summary of most important increase (+) and decrease (−) responses by individual plant species to N fertilization at 20 lb N/acre annually and to repeated heavy grazing in individual months*

Group and species	N fertilization[1]	Months of repeated heavy grazing[2]											
		J	F	M	A	M	J	J	A	S	O	N	D
Desirable species:													
Blue grama	−				+	+	+	+		−			
Scarlet globemallow						−	−		+				+
Sand dropseed	−						+			−			
Needleandthread				+		−	−	−					+
Western wheatgrass	+						−			+			
Scarlet gaura						+	−	−	−	+			
Russianthistle[3]	+	+		−	−				−			+	+
Undesirable species:													
Plains pricklypear	−				−			−	−	+	+		
Red threeawn	−					+		−	−	−			
Slimleaf goosefoot	+												
Sixweeks fescue						−	−	+	+	−	−	−	−
Prairie pepperweed[3]	+	+	+	+	+		−			−			
Smallflower cryptantha[3]	+				+	−	−						
Tansyleaf aster	+			+		−			+	−			

[1] Mean response to N fertilizer averaged across months of grazing and years of observation.

[2] Mean response to repeated heavy grazing averaged across years of observation and N fertilizer, except as noted in footnote 3.

[3] Differences among the months of repeated heavy grazing occurred only on fertilized pastures for these 3 species.

in the months when plant growth was prevented by cold temperatures (table 18). However, the mixture of responses by desirable and undesirable species prevents the selection of a time when heavy grazing may be uniquely beneficial for range improvement. By weight of evidence, heavy grazing in April, May, and June appears most unfavorable because of its detrimental effects to cool-season perennials and its reduction of stocking rates. Heavy grazing in September appears most favorable because it favored cool-season perennials and provided the best overall control of annual species. The best forage quality, as interpreted from animal daily gains, was obtained in June and July; the greatest herbage production, as interpreted from animal days of grazing, was obtained in August and September.

Heavy grazing in short seasons caused more increases than decreases in the stands of plant species. In most cases, the effects were attained only in combination with "wet" weather conditions and sometimes only in combination with N fertilizer. The most important effects were the decreases of plains pricklypear, red threeawn, and sixweeks fescue; and the increases of scarlet globemallow, needleandthread, scarlet gaura, and Russianthistle. The summary of responses in table 18 should serve as a guide to the effects of various seasons of heavy grazing.

Criteria for Range Condition Classification

A previous paper documented and described various vegetation-soils relations and discussed the problem and need for range site classification (*23*). That paper also pointed out that a previous bulletin (*28*) incorrectly classified site differences as differences in range condition. Vegetational differences within sites were not sufficiently correlated with different intensities of grazing to justify any framework for range condition classification.

The present study was established on a single range site to determine the effects of repeated heavy grazing in individual months. Grazing could not have been more severe without endangering the lives of the cattle. Nevertheless, the stands of both perennial and annual plant species increased and decreased with weather conditions to a much greater degree than in response to the months of repeated heavy grazing. Those weather-induced changes conflict seriously with conventional concepts of range condition classification, because range condition generally is interpreted as an index of the severity of grazing. This study indicated that there is no ecological basis for visual recognition and separation of vegetation changes induced by grazing from those induced by weather.

The essential criteria for evaluating range condition on upland soils of the shortgrass plains is that of the thickness of the stand of blue grama on the coarser textured soils and that of blue grama and buffalograss on the finer textured soils. A serious thinning of the stand of blue grama requires concern and management decisions. Such thinning has been caused by weather, but has not been caused by grazing, which on the contrary tends to thicken the stands. With good stands of blue grama, the stands of all other species, perennials and annuals alike, seem quite immaterial for either forage production or soil conservation. Therefore, the stands of other species may be judged from a husbandry point of view rather than from an ecological point of view. For example, range condition standards that included the annual plant species would lead alternately to dismay and pride in range condition because the annuals come and go with the weather. To a lesser extent, the status of plains pricklypear, scarlet globemallow, red threeawn, western wheatgrass, sand dropseed, and needleandthread in range condition standards would lead to similar misconceptions about the role of grazing animals.

Due to the great effects of weather, conventional range condition classification on shortgrass plains serves no useful purpose. The goal must first be to maintain a good stand of blue grama and bring it back when drought causes serious thinning. Secondly, one should prevent close grazing in April, May, and June to obtain best herbage production and maintain the stands of desirable cool-season species. In addition, the range manager will wish to limit undesirable species such as red threeawn, plains pricklypear, and many of the annual species. Bement's stocking rate guide (*3*), which requires a standing crop of herbage amounting to 300-lb/acre dry weight at all times, can be used to attain those goals, except that of controlling undesirable species. The main limitation to the requirement of a 300-lb/acre standing crop is that it would essentially eliminate grazing in April and May, unless a pasture was reserved for grazing only at that time.

The Seed Theory of Range Improvement

In recent years, it has become popular to explain and justify certain rangeland systems of grazing in terms of seed production, planting of seed by trampling, and seedling establishment. These explanations have become so widely popular that they may be identified by the label "seed theory of range improvement."

Unfortunately, the proponents of the seed theory fail to validate the explanations with direct factual data. Only circumstantial evidence relating to increases in herbage production and improvements in botanical composition by weight have been offered. Because the circumstantial evidence may be explained in other ways, it seems appropriate to direct attention specifically to the matter of the seed theory.

The ecological data obtained in this study reveal plant responses to seasonal heavy grazing that may be interpreted as effects on seed production, seed dissemination, planting of seed, and seedling establishment. However, in each case the species involved was either an annual or a pioneering-type perennial. Increases by such species are associated with deterioration in range condition or with early stages of secondary succession rather than with later stages of range improvement. Increases by dominant and subdominant perennial species seemed to relate almost entirely to physiological, morphological, and climatological factors.

In a much broader ecological context than may be represented by plant responses on shortgrass plains, the role of seed in ecological explanations is most substantial and profound at the level of earliest stages of secondary plant succession. Furthermore, attempts to duplicate nature by broadcasting seeds of native dominant perennial grasses on untilled, depleted rangeland, with or without trampling, have failed. Even on tilled soils, broadcasting of seed generally is a waste of time on semiarid rangelands. Although such negative arguments cannot disprove the seed theory as used to justify grazing systems, they do point out the need for positive and direct factual data. If the seed theory of range improvement is true and ecologically operational, it deserves to be validated directly by plant species and range sites. On the other hand, if it is a myth, it must be recognized as such to let the facts arise.

When semiarid rangeland has been deteriorated to such a degree that the dominant perennial species are gone, or even extremely rare, there is great trouble indeed. However, where they remain in sufficient abundance to justify expectations of reasonable progress in range improvement, attention to their growth requirements, rather than to planting of seed by trampling, would appear most realistic.

Maximization of Returns from N Fertilizer

Applications of N fertilizer at 20-lb N/acre annually for 7 years increased animal daily gains, liveweight gains per acre, and stocking rates. The returns from N fertilizer were maximized by grazing with yearling cattle in June through September. Under those conditions, fertilization increased the stocking rate by 6.8 animal-unit days per acre, yearling gains by 0.34 lb/day, and yearling liveweight gains by 22 lb/acre. This increase alone is greater than the average productivity of unfertilized pastures stocked moderately through the warm-season months May through October. Moderate stocking on unfertilized pastures averaged over 23 years provided 6.9 animal-unit days of grazing and just 15 pounds of liveweight gain per acre. Each additional pound of liveweight gain obtained by fertilization cost about 15 cents for the purchase and application of N fertilizer and returned over 40 cents at market prices prevailing in 1972.

Fertilizer rates should not exceed 20-lb N/acre because N increased the severity of drought in dry summers and caused serious thinning of the stands of blue grama, which is the dominant perennial grass on shortgrass plains. A rate of 40-lb N/acre applied in 2 consecutive years when summer precipitation was deficient killed nearly all of the blue grama. Even the 20-pound rate was serious in a very dry summer. To minimize damage to blue grama, N fertilizer should not be applied after a dry summer.

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