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ROGLER, G.A. LORENZ, R.J. 1 OF 1

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PASTURE PRODUCTIVITY OF CRESTED WHEATGRASS AS INFLUENCED BY NITROGEN FERTILIZATION AND ALFALFA

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CONTENTS

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PASTURE PRODUCTIVITY OF CRESTED WHEATGRASS AS INFLUENCED BY NITROGEN FERTILIZATION AND ALFALFA

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The value of crested wheatgrass (*Agropyron desertorum* [Fisch. ex Link] Schult.) as spring pasture to supplement native range or as full-season pasture in some areas is well documented for the northern Plains and much of Western United States and Canada (*2, 8, 10, 16, 17, 18, 25, 26,*).[1] Most studies that have shown the pasture potential of this grass have also shown that production decreases as age of stand increases. The purpose of this present study was to evaluate crested wheatgrass for spring grazing when unfertilized, when fertilized with nitrogen (N), and when used in mixture with alfalfa.

Animal responses were measured in terms of gains per acre and per head and by dry matter intake. Plant responses were measured in terms of carrying capacity in steerdays grazing per acre, dry matter production at various stages of growth, protein content, total digestible nutrients (TDN) per acre, and palatability. Changes in soil organic carbon, nitrogen, pH, and phosphorus under pastures receiving the various treatments were also measured.

EXPERIMENTAL AREA AND CLIMATE

The study was conducted at the Northern Great Plains Research Center, Mandan, N. Dak. Elevation at the study site is 1,750 feet above sea level. Experimental pastures were seeded on an area that was broken from native sod in 1921 and seeded to tame pasture that same year. The area remained in tame pasture until the present study was established. The slope of the land is from level to approximately 2 percent toward the west. Long dimension of the experimental pastures was from east to west. Soil of the site is classified as Temvik silt loam. It was developed over calcareous glacial till and has a dark grayish-brown surface. Soil constituents will be discussed on page 21 under "Results and Discussion."

The climate of the area is semiarid. Temperatures reach extremes in both winter and summer and there are strong drying winds and frequent droughts. Precipitation during the 10-year period of the study is shown in table 1. The most effective precipitation was in April, May, and June when the crested wheatgrass was making the major

[1] Italic numbers in parentheses refer to Literature Cited, page 26.

TABLE 1.—*Precipitation in inches recorded at the Northern Great Plains Research Center, Mandan, N.Dak., from July 1955 through June 1965*

Crop year	Precipitation recorded in—												Total precipitation in—	
	July	August	September	October	November	December	January	February	March	April	May	June	12 months	April to June
1955–56	3.88	1.70	2.93	0.22	0.99	0.19	0.48	0.05	1.03	0.08	3.45	3.61	18.61	7.14
1956–57	2.65	3.13	.46	.14	1.47	.09	.42	.11	.22	1.51	3.11	2.72	16.03	7.34
1957–58	1.97	1.68	.99	2.15	.17	.33	.18	.90	.22	.86	1.35	4.18	14.98	6.39
1958–59	1.48	.90	.29	.46	1.62	.20	.21	.23	.21	.31	1.91	2.44	10.26	4.66
1959–60	.20	2.20	1.93	1.21	.76	.36	.13	.01	.41	.49	3.23	6.01	16.94	9.73
1960–61	.70	3.32	.22	.01	.22	.23	.16	.17	.07	1.68	.97	1.88	9.63	4.53
1961–62	1.89	.77	3.69	.44	0	.40	.22	.22	.60	.57	4.82	2.82	16.44	8.21
1962–63	2.84	1.29	.59	.57	.28	.13	.12	.35	.40	1.62	2.89	5.37	16.45	9.88
1963–64	3.91	1.72	.63	1.02	0	.25	.56	.09	.17	2.68	1.08	5.75	17.86	9.51
1964–65	1.64	.95	.96	.10	.58	.26	.35	.12	.30	1.73	4.67	5.02	16.68	11.42
10-year average	2.12	1.77	1.27	.63	.61	.24	.28	.23	.36	1.15	2.75	3.98	15.39	7.88

part of its seasonal growth. The years 1959 and 1961 were exceptionally dry and unfavorable for the growth of grass. The years 1962 and 1965 were exceptionally favorable for growth because of high May precipitation.

PROCEDURE

Seeding and Treatments

Approximately 37 acres of land for the experiment was plowed in late summer of 1953. After the land was fallowed, it was seeded with crested wheatgrass on September 20 and 21, 1954, at 10 pounds per acre with a standard single-disk grain drill having a 7-inch row spacing. The seeded area was divided into eight 4.54-acre pastures (each 157 feet by 1,260 feet).

There were four treatments, each with two randomized replications (pastures). The treatments were:

(1) Crested wheatgrass with no fertilizer (0–N),

(2) Crested wheatgrass with 40 pounds of nitrogen per acre (40–N),

(3) Crested wheatgrass with 80 pounds of nitrogen per acre (80–N), and

(4) Crested wheatgrass-alfalfa mixture with no fertilizer.

Fertilizer as ammonium nitrate was applied with a broadcast spreader in mid-October each year. 'Ladak' alfalfa (*Medicago sativa* L.) was overseeded on two of the pastures with a single-disk drill at 2 pounds per acre on April 15, 1955.

Livestock and Pasture Management

High-quality yearling Hereford steers, averaging 524 pounds per head starting weight over the 10 years, were used as experimental animals. Their starting weight ranged from a high of 575 pounds per head in 1959 to a low of 475 pounds per head in 1965. Stocking rates at the beginning of the season were based on forage yields taken at that time. There were never fewer than four steers on any pasture at any time. Extra steers were added or removed as needed to fully utilize the pastures uniformly in periods of high or low production. The average number of steers per pasture was:

Treatment:	*Number*
0–N	4.88
40–N	7.41
80–N	7.93
Mixture	5.73

Gains per acre were based on the total gains made by the steers left on the pastures the full season and by those added or removed. Theoretical gains (average daily gain of season-long steers × steerdays of grazing) based only on the daily gains of the season-long steers were not used because of the close association with actual gains.

All weights were of individual steers. Weights used in allotting steers at the beginning of the season were an average of weights on 3 consecutive days. Before and during the weigh-in period, the steers were preconditioned on pastures of new green grass. Steers were allotted by weight so the average weight per steer for each pasture was the same within each year. During the grazing period all steers were weighed every 2 weeks or oftener as needed. Water was withheld from the animals overnight before early morning weighing. Final weights were the average of 2 consecutive days.

Grazing began on May 16 each year. The amount of new leaf growth on that date varied from year to year, depending upon the earliness of the season. Growth ranged from 4 to 7 inches on the unfertilized pastures and from 6 to 10 inches on the fertilized. Cattle remained on the pastures for 25 to 55 days, depending upon forage production and the time necessary to utilize the available forage. An effort was made to completely utilize all pastures by the time the grass became less palatable and less nutritious, approximately July 1.

Loose livestock salt was provided free choice for the cattle at all times. Horn flies were controlled as needed.

Forage Production and Consumption

Eight 4- by 7-foot cages and four 8- by 8-foot cages were placed at random in each of the pastures at the beginning of the grazing season. Forage yields for the determination of pasture production for the period the cattle were on the pastures were obtained from clippings inside the smaller cages. Clippings from the larger cages were taken at approximately dough stage and considered to be hay yields. All yields determinations were made on a dry matter (ovendry to 70° C.) basis. Clippings were taken outside the cages at the beginning of the season and both inside and outside each cage when cattle were removed. Forage consumption was assumed to be the difference in weight between the inside and outside clippings. Clippings were made with a sickle bar mower at a height of 1 inch during the first 5 years of the study. After that, clippings were made with a rotary mower with pickup attachment at a height of 2 inches in two 2- by 100-foot strips in the grazed areas of the pasture and within each cage for the length of the cage. Since the clipping height of the rotary mower was 2 inches, 2-foot square areas were clipped at four random locations at the soil surface in the grazed areas within each rotary-mowed strip and at one location in the cages. The total of the surface and rotary clipping made up the total yield. All hay yields were taken at a 1-inch height. The crested wheatgrass and alfalfa components of the mixed pastures were separated for yield determinations.

Four additional 4- by 7-foot cages were placed in paired positions in each pasture in 1963 to determine the effects of phosphorus (P) fertilization. Phosphorus was surface applied as treble superphosphate in one cage of each pair at the rate of 44 pounds of phosphorus per acre on March 27. Clippings at a 1-inch height were taken on July 15.

Protein and Total Digestible Nutrients

Clippings for crude protein determinations were taken at the beginning and end of the grazing season and at hay stage each year. Nitrogen content of the forage (not including nitrate) was determined by a modified Kjeldahl method (*1*) and crude protein calculated as 6.25 × N.

Total digestible nutrients (TDN) per acre for the various treatments was based on the nutritional needs of the animal for maintenance and gain in accordance with the method used by the National Research Council (*13*).

Soil Water and Soil Changes

Gravimetric soil water samples were taken in the early spring, at the time cattle were removed, and again in the fall. Two soil cores were taken to determine the amount of soil water by foot increments to a depth of 6 feet at each of three locations per pasture in 1958, 1959, and 1960.

Soil samples were taken at 0- to 6-inch, 6- to 12-inch, and 12- to 24-inch depths in two locations in each pasture at the time of seeding in 1954 and at the end of the experiment in 1965. The 1954 samples were stored and chemical determinations of all samples were made in 1966. Organic carbon was determined by a modified Walkley-Black procedure (*9*), total nitrogen (N), including NO_3, by the Kjeldahl method (*1*), pH from a saturated paste (*24*), and sodium bicarbonate-soluble phosphorus ($NaHCO_3$-soluble P) by the method of Olsen and others (*14*).

RESULTS AND DISCUSSION

Beef Production Per Acre

Relative beef production per acre from the various treatments was the most important economic measure of pasture performance in the study. With results from only two replications, however, plus the high variation in animal gains between replications, statistical significance was not obtained between small differences within years. Wide differences were obtained when averages for all years were considered. Significant differences between treatments were sufficiently high to show the effects of the treatments on beef production per acre.

At the beginning of the study (1956) beef production was high from all treatments (table 2), but was highest from the 80–N treatment. Production from the 0–N treatment dropped sharply beginning the second year and declined through the fourth year with yearly fluctuations thereafter. Beef production from the fertilized pastures exceeded that from the unfertilized pastures every year after the first year. The differences became greater as the stands became older, with the greatest difference the 10th year of study (1965), when spring precipitation was higher than it had been any other year. Production from the unfertilized pastures dropped in 1959 and 1961, years of low precipitation, but relative response to high precipitation in 1962 and 1965 was not as great from the unfertilized pastures as from the fertilized. Contrary to what was expected, no significant ($P>.05$) relation was found between April, May, and June rainfall and beef production from any of the treatments.

TABLE 2.—*Beef production per acre from yearling steers grazing crested wheatgrass pastures receiving various treatments* [1]

Year	Beef production from yearling steers on pastures treated with—			
	0–N	40–N	80–N	Mixture
	Pounds/acre	*Pounds/acre*	*Pounds/acre*	*Pounds/acre*
1956	172.9 a	182.8 a	244.0 b	187.2 a
1957	106.8 a	195.5 b	201.6 b	152.6 ab
1958	96.9 a	175.6 bc	191.0 c	138.8 b
1959	82.1 a	129.4 b	111.2 b	77.7 a
1960	99.7 a	143.2 b	144.3 b	122.8 ab
1961	65.6 a	106.8 b	108.5 b	93.6 b
1962	108.4 a	193.8 b	192.2 b	161.9 b
1963	70.5 a	150.4 b	187.2 c	126.1 b
1964	105.7 a	173.5 c	150.9 bc	121.7 ab
1965	98.0 a	237.4 c	232.4 c	171.8 b
Average	100.7 a	168.8 c	176.3 c	135.4 b

[1] Within each year, means followed by same letter do not differ significantly at the 5-percent level (*5*).

Beef production from the crested wheatgrass-alfalfa pastures significantly ($P<.05$) exceeded that from the 0–N pastures 5 out of 10 years and equaled it in each of the other 5 years. Only in 3 out of 10 years did production from the mixture fall below that from the 40–N pastures. In only 2 out of 10 years did production from the 80–N pastures exceed that from the 40–N pastures.

The value of nitrogen fertilizer and alfalfa in the mixture in maintaining production of crested wheatgrass is evident from the data. Beef production from the 40–N pastures increased 55 percent and production from the 80–N pastures and the mixtures decreased slightly from 1956 to 1965. However, production from the 0–N pastures decreased 42 percent over that same 10-year period.

As an average for all years, differences in beef production from the 40–N and the 80–N pastures were small and not significant. Production from the 40–N pastures was 68 percent higher than that from the 0–N pastures and 25 percent higher than that from the mixtures.

Daily and Seasonal Gains Per Head

Daily gains of the steers grazing on all pastures receiving various treatments were high (table 3), indicating the high nutritive quality of crested wheatgrass in the spring. Since the steers were removed from the pastures before there was a shortage of forage and while nutritive qualities were still at a high level, gains were high for the entire grazing period. There was no statistical difference ($P>.05$) in daily gains between treatments in any year, however, variation between replications and years was high. The crested wheatgrass-alfalfa

TABLE 3.—*Daily gain of yearling steers grazing crested wheatgrass pastures receiving various treatments*

Year	Daily gain in pastures treated with—				Average
	0-N	40-N	80-N	Mixture	
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1956	2.71	2.34	2.98	2.83	2.72
1957	2.31	2.53	2.29	3.30	2.61
1958	2.93	2.90	2.56	3.00	2.85
1959	2.98	2.94	2.52	2.35	2.70
1960	2.33	2.30	2.25	2.57	2.36
1961	2.38	2.77	2.82	2.84	2.70
1962	2.45	2.43	2.11	2.90	2.47
1963	2.67	2.30	2.46	2.55	2.50
1964	3.01	2.65	2.28	2.77	2.68
1965	2.79	3.13	3.05	3.09	3.02
Average	2.66	2.63	2.53	2.82	2.66

mixture tended to produce somewhat higher daily gains in 1957, 1960, and 1962, but these were offset by lower gains in other years and were not as high as those shown by Campbell (*3*).

Daily gains on crested wheatgrass from May 15 to June 30 were slightly lower than those on adjacent native range for the same period under the same nitrogen treatments. During an 8-year period (1958–65) average daily gains per head were:

	Gains on native range	Gains on crested wheatgrass
Treatment:	*Pounds*	*Pounds*
0-N	2.70	2.69
40-N	2.82	2.68
80-N	2.92	2.51

After steers were removed from the crested wheatgrass pastures, they were placed together on reserve native range and grazed at a moderate rate for the rest of the 140-day summer grazing season. Average daily gains while on native range were approximately 1.5 pounds per head. Total average gains per head on crested wheatgrass for 10 years were:

Treatment:	*Pounds*
0-N	94.0
40-N	105.1
80-N	101.7
Mixture	107.3

Total summer gains per head, determined by adding the gain made on native range the rest of the season, were:

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Treatment:	*Pounds*
0-N	255.5
40-N	255.6
80-N	255.7
Mixture	264.8

The data show that nitrogen fertilizer neither increased nor decreased gains per head and that the mixture tended to increase gains slightly. The advantage in increased beef production from fertilization was due to the increased number of animals per unit of land and not to the increased gains per head.

Carrying Capacity

For the purpose of this study, carrying capacity was considered to be the maximum number of animals that could be supported on the various treatments for the spring with complete utilization and without a shortage of forage, reduced gains, or damage to the vegetation. Carrying capacity values obtained in this study are important only as an indication of the amount of grazable forage. When considered in relation to gains per acre under the various treatments, they are important in providing a measure of the relative value of the treatments.

The number of acres required per head for the number of days grazed each year are given in table 4. More acres were required per head as stands of unfertilized crested wheatgrass became older. Carrying capacity of fertilized grass was more nearly maintained from year to

TABLE 4.—*Acres required to carry a yearling steer for given number of days on crested wheatgrass pastures receiving various treatments*

Year	Acres and number of days required to carry yearling steer in pastures treated with—							
	0-N		40-N		80-N		Mixture	
	Acres per head	Days grazed	Acres per head	Days grazed	Acres per head	Days grazed	Acres per head	Days grazed
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1956	0.68	45	0.57	45	0.56	45	0.68	45
1957	.76	35	.59	45	.55	45	.76	35
1958	.91	30	.59	35	.49	35	.76	35
1959	.91	25	.57	25	.57	25	.76	25
1960	1.00	40	.67	40	.67	40	.86	40
1961	.91	25	.65	25	.65	25	.76	25
1962	.97	45	.61	55	.52	55	.80	45
1963	1.14	30	.68	45	.57	45	.91	45
1964	1.14	40	.66	45	.66	45	.91	40
1965	1.14	40	.57	45	.57	45	.80	45
Average	.96	36	.62	40	.58	40	.80	38

year but capacity of the crested wheatgrass-alfalfa mixture dropped slightly as stands became older.

A more accurate picture of carrying capacity was obtained by considering both the number of animals per acre and the days grazed, referred to here as steerdays of grazing per acre. Data in table 5 show wide differences between treatments within years and between years within treatments. On the basis of this study, considering all years, carrying capacity of the 40–N pasture was 72 percent higher than that of the 0–N pastures and 37 percent higher than that of the mixtures. Carrying capacity of the mixtures was 26 percent higher than that of the unfertilized pastures. On the average, carrying capacity of th^ 80–N pastures was higher than that of the 40–N pastures, but this advantage disappeared toward the end of the study.

TABLE 5.—*Steerdays of grazing per acre produced on crested wheatgrass pastures receiving various treatments* [1]

Year	Steerdays of grazing produced on pastures treated with—				Average
	0–N	40–N	80–N	Mixture	
	Number	*Number*	*Number*	*Number*	*Number*
1956	66.1	77.7	82.6	66.1	73.1
1957	46.3	76.0	82.6	46.3	62.8
1958	33.0	59.5	71.6	46.3	52.6
1959	27.5	44.1	44.1	33.0	37.2
1960	39.6	59.5	59.5	46.3	51.2
1961	27.5	38.5	38.5	33.0	34.4
1962	46.3	90.3	105.7	56.2	74.6
1963	26.4	66.1	79.3	54.0	56.5
1964	35.2	68.3	68.3	44.1	54.0
1965	35.2	79.3	79.3	56.2	62.5
Average	38.3	65.9	71.2	48.2	55.9

[1] Steerdays indicate the average number of steers per acre × days of grazing.

Forage Production and Consumption

Forage yields were taken at the beginning of the grazing season as a guide to initial stocking rates (table 6). There was a wide difference in amount of new growth on May 16 from year to year, depending upon spring temperatures, precipitation, treatment, and growing conditions the previous fall. In general the data show that approximately 50 percent more forage was available on the fertilized pastures at the time grazing began than on the unfertilized pastures. In 4 of the 9 years in which clippings were taken at the beginning of the season there was no significant increase in forage due to fertilization, even though the fertilized pastures appeared to have more growth because of the dark-green leaves. At the beginning of the season, forage production was only slightly higher from the crested wheatgrass-alfalfa pastures than from the unfertilized pastures.

A number of workers in the northern Great Plains have shown increased forage production from crested wheatgrass fertilized with nitrogen (*11, 19, 20, 23*). Data from the present study also show wide increases in production from the use of 40 and 80 pounds of N per acre (table 6). Clippings made from cages when cattle were removed from the pastures showed that, when compared with unfertilized pastures, production was 59 percent higher from 40-N pastures, 79 percent higher from 80-N pastures, and 29 percent higher from the mixtures. The level of forage production maintained over 10 years was also higher in the fertilized pastures. Forage production was highest the 10th year.

The relation between forage and beef production per acre over the 10 years is indicated by a highly significant ($P<.01$) r value of 0.77. Approximately 60 percent of the variation in beef production could

TABLE 6.—*Forage production per acre from crested wheatgrass pastures receiving various treatments and clipped at beginning and end of grazing season* [1] [2]

Time of year and year	Forage production from pastures treated with—			
	0-N	40-N	80-N	Mixture
At beginning of grazing season:	*Tons/acre*	*Tons/acre*	*Tons/acre*	*Tons/acre*
1956				
1957	0.30 a	0.45 b	0.53 b	0.31 a
1958	.48 a	.65 a	.77 a	.57 a
1959	.51 a	.72 a	.64 a	.52 a
1960	.51 a	.71 a	.63 a	.58 a
1961	.30 a	.42 b	.45 b	.32 a
1962	.55 a	.83 a	.70 a	.55 a
1963	.45 a	.72 b	.70 b	.46 a
1964	.42 a	.66 c	.61 bc	.50 ab
1965	.38 a	.76 c	.67 c	.56 b
Average	.43 a	.66 c	.63 c	.48 b
At end of grazing season:				
1956	1.46 a	1.59 a	1.67 a	1.38 a
1957	.67 a	1.07 c	1.45 d	.94 b
1958	.72 a	1.03 b	1.09 b	.69 a
1959	.51 a	.79 a	.69 a	.62 a
1960	.68 a	1.13 a	1.14 a	.81 a
1961	.58 a	.78 a	.91 a	.72 a
1962	1.33 a	2.06 a	2.35 a	1.95 a
1963	.93 a	1.64 c	1.97 d	1.27 b
1964	.83 a	1.63 b	1.89 b	1.14 a
1965	1.04 a	2.13 c	2.44 d	1.68 b
Average	.87 a	1.38 c	1.56 d	1.12 b

[1] The grazing season began on May 16 each year and ended at various dates from June 10 to July 10, depending on the year and treatment.

[2] Within each year, means followed by same letter do not differ significantly at the 5-percent level (*5*).

be accounted for by the variability in forage production. Both forage and beef production were low in the dry years of 1959 and 1961 and high in the wet years of 1962 and 1965.

In spite of an attempt to graze all treatments uniformly by applying equal grazing pressure, there was considerable variation in utilization within each year. The percentage utilization based on differences between clippings taken inside and outside cages at the end of the season was more nearly uniform between treatments than was the weight of the forage left ungrazed in each treatment (table 7). On the average, utilization was lower from the 0–N treatment than from the other treatments because less forage was produced and consumed in relation to the amount of forage remaining on the ground when cattle were removed. At the end of the season 42 percent more forage remained on the fertilized pastures than on the unfertilized.

TABLE 7.—*Forage left ungrazed and utilization of crested wheatgrass pastures receiving various treatments*

Year	Forage left ungrazed in pastures treated with—				Utilization of pastures treated with—			
	0–N	40–N	80–N	Mixture	0–N	40–N	80–N	Mixture
	Pounds/acre	*Pounds/acre*	*Pounds/acre*	*Pounds/acre*	*Percent*	*Percent*	*Percent*	*Percent*
1956	1,911	1,674	2,367	1,368	35	47	29	50
1957	359	717	846	556	73	66	71	70
1958	747	555	624	351	48	73	71	75
1959	177	267	257	252	83	83	81	79
1960	291	618	786	460	79	72	65	72
1961	670	924	913	691	42	40	49	52
1962	1,270	1,482	1,647	1,388	52	64	65	65
1963	1,232	1,413	1,671	1,114	34	57	58	56
1964	725	1,352	1,360	935	56	58	64	59
1965	947	2,053	2,338	1,288	54	52	52	62
Average	833	1,106	1,281	840	52	60	60	63

Apparent daily forage consumption (forage disappearance) per head and the ratio of consumption to beef production varied widely between years and treatments (table 8). Since yearling steers of similar weight and condition were used each year and since they were removed from the pastures while forage was still adequate, daily consumption per head should have been similar each year. A major part of the error in determining consumption appeared to be from inadequate sampling on which consumption values were based. The difference in weight of clipped forage from inside and outside cages at the end of the grazing season did not accurately measure the consumption within years. The high variability from year to year indicates the questionable nature of the clipping method used to determine consumption values.

TABLE 8.—*Forage consumed daily and ratio of forage consumed to beef produced on crested wheatgrass pastures receiving various treatments*

Year	Forage consumed daily on pastures treated with [1]—				Ratio of forage consumed to beef produced on pastures treated with—			
	0-N	40-N	80-N	Mixture	0-N	40-N	80-N	Mixture
	Pounds/head	*Pounds/head*	*Pounds/head*	*Pounds/head*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1956	15.5	19.2	11.6	21.0	5.9	7.2	3.9	7.4
1957	21.2	18.6	24.9	21.1	9.2	7.2	10.2	8.7
1958	21.1	25.2	21.5	19.6	7.2	8.5	8.1	7.4
1959	30.5	29.7	25.4	26.2	10.2	10.1	10.1	12.5
1960	26.8	27.4	25.1	22.5	10.7	11.3	10.4	9.4
1961	17.7	16.2	23.5	21.9	7.4	8.4	6.9	6.7
1962	29.6	29.1	28.8	34.0	12.7	13.5	15.9	15.7
1963	23.6	28.2	28.6	25.1	8.8	12.4	12.1	11.2
1964	26.3	27.7	35.4	24.8	8.8	10.9	16.0	11.1
1965	32.2	27.7	31.9	36.9	11.6	9.3	10.9	12.2
Average	24.5	24.9	25.7	25.3	9.1	9.8	10.4	10.3

[1] Apparent consumption (forage disappearance) was based on difference between clippings taken from inside and outside cages at the end of the grazing season.

Values for the amount of forage required to produce a pound of beef were also highly variable, not only because of differences in apparent consumption but also because of variations in gains. When considering the average consumption values for all years and treatments, however, values for both daily consumption per head and the ratio of forage produced to beef produced were similar to those obtained by other workers.

Whitman and others (*25*) reported a daily forage consumption of 17 pounds per head on crested wheatgrass and 17.5 pounds on crested wheatgrass-alfalfa mixture. Since their daily gains per head were lower than those in the present study, the forage requirement per head per day was lower. In the present study the 10-year average requirement for yearlings on all treatments gaining an average of 2.7 pounds per day per head was 9.9 pounds of forage per pound of gain. Feed requirement indicated by the National Research Council (*13*) for normal-growth yearlings is 10.5. At the rate of gain made by steers in the present study, the value obtained is in line with values indicated by the National Research Council.

Grazing apparently removed little or no forage below a 2-inch height as measured in 1961 and from 1963 through 1965 (table 9). Yields below 2 inches in grazed areas were only slightly less than those in caged areas where there had been no grazing. If grazing caused the plants to stool out or become more prostrate in growth habit, then some grazing might have occurred below 2 inches without reducing the relative yield compared with that below 2 inches in caged areas. Forage yields below 2

TABLE 9.—*Forage production at end of season below and above a 2-inch height of cutting in grazed and caged areas in crested wheatgrass pastures receiving various treatments*

Treatment and year	Forage production from—			
	Grazed areas	Caged areas		
	Below 2 inches	Below 2 inches	Above 2 inches	Total
	Pounds/acre	*Pounds/acre*	*Pounds/acre*	*Pounds/acre*
0-N:				
1961	510	569	587	1, 156
1963	858	632	1, 222	1, 854
1964	562	637	1, 014	1, 651
1965	561	756	1, 323	2, 079
Average	623	649	1, 037	1, 686
40-N:				
1961	668	674	874	1, 548
1963	571	709	2, 565	3, 274
1964	657	713	2, 533	3, 246
1965	719	858	3, 392	4, 250
Average	654	739	2, 341	3, 080
80-N:				
1961	668	772	1, 046	1, 818
1963	756	816	3, 120	3, 936
1964	643	781	2, 999	3, 780
1965	739	933	3, 936	4, 869
Average	702	826	2, 775	3, 601
Mixture:				
1961	527	629	814	1, 443
1963	578	659	1, 872	2, 531
1964	643	795	1, 490	2, 285
1965	657	653	2, 706	3, 359
Average	601	684	1, 721	2, 405

inches were increased by fertilization, but the major increase due to fertilization was above a 2-inch height; consequently, the additional forage was available for grazing. The amount of forage above the 2-inch height was 62 percent from the 0-N treatment, 76 percent from the 40-N, 77 percent for the 80-N, and 72 percent for the mixture.

Hay yields taken when the seed was in the dough stage were not significantly increased ($P > .05$) by fertilization or by alfalfa until the 5th year of production (1960) (table 10). In 1961 yields between treatments again were not significantly increased, but from 1962 through 1965 hay yields from the fertilized treatments were much higher than from the unfertilized. As with all other forage measure-

TABLE 10.—*Forage production per acre from crested wheatgrass pastures receiving various treatments and cut at dough stage (hay)* [1]

Year	Forage production from pastures treated with—			
	0–N	40–N	80–N	Mixture
	Tons/acre	*Tons/acre*	*Tons/acre*	*Tons/acre*
1956	1.47 a	1.59 a	1.67 a	1.38 a
1957	.97 a	1.46 a	1.79 a	1.11 a
1958	.97 a	1.58 a	1.45 a	1.35 a
1959	.43 a	.69 a	.55 a	.56 a
1960	.72 a	1.28 bc	1.38 c	1.08 b
1961	.66 a	.94 a	.91 a	.77 a
1962	1.02 a	2.02 b	2.63 c	2.16 b
1963	.70 a	1.59 c	1.90 d	1.09 b
1964	.77 a	1.79 b	1.86 b	1.33 ab
1965	.75 a	2.31 b	2.20 b	1.38 a
Average	.84 a	1.52 c	1.63 c	1.22 b

[1] Within each year, means followed by same letter do not differ significantly at the 5-percent level (*5*).

ments, yields from the 0–N treatment decreased after the 1st year of production and tended to level off, with yearly fluctuations after that time. Yields from the 40–N and 80–N treatments were maintained or increased. Yields from the 40–N treatment were higher the 10th year than any other year; yields from the 80–N treatment were higher the 7th year. Alfalfa in mixture with crested wheatgrass helped maintain hay production but yields were lower than from fertilized treatments. The average increased yields in hay from treated pastures, when compared with yields from 0–N pastures, were:

Treatment:	*Percent*
40–N	81
80–N	94
Mixture	45

Residual effects of nitrogen fertilizer on hay yields were measured in 1966 and 1967. Fertilizer was last applied in the fall of 1964. April–June precipitation was 5.73 inches in 1966 and 4.97 inches in 1967—both much below the 1956–65 average. Hay yields were:

Treatment:	*1966 Ton/acre*	*1967 Tons/acre*
0–N	0.37	0.44
40–N	.61	.63
80–N	.93	1.26
Mixture	.63	.91

Marked response to residual fertilizer was apparent both years. Forage from the mixture was approximately 30 percent alfalfa and 70 percent grass both years. Yields from the mixture continued to be higher than those from the unfertilized treatment.

Protein

Crude protein has long been considered a measure of quality in forages. While increased emphasis has been placed in recent years on energy derived from forages, protein content still remains a good measure of the relative nutritive value of various types of pasture and forage. According to Sullivan (*21*), the percentage of crude protein is highly correlated with the percentage of digestible protein. He obtained an r value of 0.99 for all protein data he studied. Crude protein content was also highly correlated with digestion coefficients of dry matter and crude protein.

Each year crude protein determinations were made of forage clipped from each pasture three times during the grazing season (table 11). Crude protein contents at all growth stages except the hay stage were in general above the minimum requirements of 9 to 10 percent for 600-pound yearling cattle as suggested by the National Research Council (*13*). Increased increments of nitrogen fertilizer increased the protein content significantly at all growth stages. The grass from the crested wheatgrass-alfalfa mixtures was slightly higher in protein than that of grass from 0–N pastures but lower than that from 40–N pastures. Protein content of the mixtures was similar to that of grass from 80–N pastures, except at the beginning of the season when protein was higher from the 80–N pastures. As the plants matured, protein content on all treatments decreased. Protein content of forage that was continuously grazed was higher than that of caged material when both were sampled on the same date. Increased protein contents due to fertilization did not significantly affect gains per head while

TABLE 11.—*Crude protein content of crested wheatgrass at three times of clipping and four growth stages in grazed and caged areas in pastures receiving various treatments*[1]

Time of clipping	Growth stage	Crude protein content in pastures treated with—					
		0–N	40–N	80–N	Mixture		
					Grass	Alfalfa	Mixture
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Start of season (May 16).	Leaves	14.08	19.10	22.34	17.58	30.22	18.91
End of grazing season in grazed areas.	Leaves and stubble.	9.58	10.42	12.54	10.45	20.63	12.33
End of grazing season in caged areas.	Flower and preflower.	8.21	9.40	11.37	8.99	19.14	11.81
Hay stage	Early dough.	7.11	8.10	9.93	7.33	16.34	9.90

[1] Values shown are the average of samples taken in two replications each year for 10 years (20 samples).

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cattle were on pasture because all these contents were above the minimum needs of the animal. It is assumed, however, that increased protein due to fertilization would increase the nutritive value of the hay when fed during periods when protein contents in the feed were near or below minimum requirements.

Total Digestible Nutrients

The amount of total digestible nutrients (TDN) per acre based both on beef production and on carrying capacity is the best measure of pasture performance of the various treatments in the present study. Values on carrying capacity and dry matter production indicate somewhat the expected beef production but are only a partial evaluation of pasture performance without supporting data. Beef production values alone without data on carrying capacity do not take into account the length of the grazing period and the ability of the pasture to maintain the weight of the animal as well as to produce net weight gain.

The committee on beef cattle nutrition of the National Research Council has compiled information on the daily nutrient requirements for maintenance and gain of various classes of beef cattle (*13*). Their formula, digestible energy (DE) $= 74.5W^{0.75} (1 + 0.59 g)$, where W is the average weight of the animal and g is the daily gain, was used to determine the production of TDN per acre from the various pastures in this study. Swift (*22*), using all the simultaneously determined TDN and DE values of mixed and roughage rations available in the literature, arrived at the average conversion factor of 2,000 kilocalories per pound of TDN. This conversion factor was used by the National Research Council. For the present study, calculated values of DE were converted to TDN to express these TDN values as weight per acre.

TDN production per acre for maintenance was calculated from the values for average number of steers per acre, average weight of steers, weight of steers per acre, TDN required daily per 100 pounds body weight, and average days grazed. TDN production per acre for gain was calculated from the values for gain per acre and TDN required per pound of gain.

The 10-year average production of TDN per acre for maintenance and gain and the total of the two values did not differ significantly between the 40–N and 80–N treatments (table 12). On the basis of total TDN production per acre, production from the 40–N treatment was 74 percent higher than that from the 0–N treatment and 29 percent higher than from the mixture; and total production from the mixture was 35 percent higher than that from the 0–N treatment. Daily TDN and DE production per acre was also higher from the fertilizer treatments, and production from the mixture was higher than that from the unfertilized treatment.

There was a highly significant ($P<.01$) positive relation between TDN production and beef production per acre with an r value of 0.95. This was expected since beef production was one of the factors used in calculating TDN. The relation between TDN and dry matter production was somewhat lower but also highly significant with an r value of 0.80. Total TDN production varied widely between treatments and between years (table 19, appendix). The level of produc-

TABLE 12.—*Production of total digestible nutrients (TDN) and digestible energy (DE) and TDN required per pound of grin from crested wheatgrass pastures receiving various treatments, 10-year averages* [1 2]

Treatment	TDN production for maintenance	TDN production for gain	Total TDN produced	TDN produced daily	DE produced daily	TDN required per pound of gain
	Pounds/acre	*Pounds/acre*	*Pounds/acre*	*Pounds/acre*	*Kilocalories/acre*	*Pounds*
0-N	150 a	225 a	375 a	10. 7 a	21, 400 a	3. 81 a
40-N	260 c	392 c	652 c	16. 3 c	32, 600 c	3. 86 a
80-N	279 c	409 c	688 c	17. 2 c	34, 400 c	3. 91 a
Mixture	188 b	317 b	505 b	13. 2 b	26, 400 b	3. 75 a

[1] Based on animal requirements calculated from the Nat. Res. Council (*13*) equation $DE = 74.5W^{0.75} (1 + 0.59\ g)$ where W = wt. of animal and g = daily gain and assuming 2,000 kilocalories of DE per pound of TDN. All values are in terms of dry matter.

[2] Means followed by same letter do not differ significantly at the 5-percent level (*5*).

tion for the fertilized treatments held up well over the 10 years, production during the last year of study (1965) being one of the highest. There was a marked loss in production from the unfertilized treatment the first 2 years. After that, production tended to fluctuate each year. Production was low from the unfertilized treatment during the last year even though precipitation was favorable for growth. The mixture maintained TDN production better than the unfertilized treatment.

On the average, the amount of TDN required to produce a pound of beef was similar for all treatments (table 12). However, the TDN requirement tended to be lower for the mixture, indicating a somewhat higher forage quality for the mixture. TDN requirements in all cases were not out of line with those indicated by the National Research Council (*13*) for cattle of similar weight making similar gains.

The data indicate that the values for the amount of forage required to produce a pound of beef (table 8) were much more erratic from year to year than were values for TDN required per pound of beef (table 19, appendix). The standard error for forage required per pound of beef was 4.8 percent of the means and that for TDN required per pound of beef was 1.3 percent.

Palatability

Miller and Terwilliger (*12*) showed that nitrogen fertilizer increased the palatability of crested wheatgrass to cattle, especially during the soft dough and seed ripe stages. In the present study intake measurements (table 8) would indicate no marked differences in the average palatability of the various treatments. However, the steers in the fertilized pastures tended to graze less uniformly. In some years the steers in the fertilized pastures were not grazing the grass as rapidly as it was developing and plants became stemmy and coarse. Patchy grazing developed, with close grazing in some spots and practically no grazing in others. The problem was the same in dry years when soil moisture was depleted more rapidly in the fertilized pastures. Patchy grazing developed in these pastures, while grazing remained quite uniform in the unfertilized pastures.

No residual effects were observed the year after patchy grazing had developed. Improved management such as increased grazing intensity or mowing might have decreased the amount of patchy grazing.

Maintenance of Alfalfa in Mixture

Whitman and others (*25*) reported that the alfalfa of the forage from pastures of crested wheatgrass-alfalfa mixture grazed with cattle decreased from 50 percent the 1st year of grazing to 4 percent the 7th. Campbell (*3*) reported that alfalfa from the same type pasture but grazed with sheep decreased gradually over a 6-year period. In the present study, also with the same type pasture but after a shorter spring grazing period than in the above two studies, alfalfa increased from 10 percent the 1st year to 37 percent the 10th (table 13). It is assumed that where the livestock were removed after a grazing period of 45 days or less, the alfalfa root reserves were restored and were sufficient to protect the plants from winter injury.

TABLE 13.—*Yields of crested wheatgrass-alfalfa mixtures and pure crested wheatgrass*[1]

Year	Forage production from— Mixture: Grass	Mixture: Alfalfa	Mixture: Alfalfa	Mixture: Total	Pure crested wheat-grass
	Pounds/acre	*Pounds/acre*	*Percent*	*Pounds/acre*	*Pounds/acre*
1956	2,470	275	10	2,754	2,933
1957	1,430	451	24	1,881	1,341
1958	1,008	373	27	1,381	1,444
1959	1,029	196	16	1,225	1,016
1960	1,160	452	28	1,612	1,353
1961	1,068	375	26	1,443	1,156
1962	2,849	1,054	27	3,903	2,643
1963	1,721	810	32	2,531	1,855
1964	1,576	708	31	2,284	1,651
1965	2,116	1,243	37	3,359	2,079
Average	1,643	594	27	2,237	1,747

[1] Clippings were taken within cages in pastures of each treatment at the end of the grazing season.

Alfalfa increased the yield of grass in the mixtures, compared with the increased yield of grass in pure stands. The yield of grass in the mixtures was less than that in pure stands, but only a part of the space in the pasture was occupied by the grass and the rest by alfalfa. If the grass in the mixtures had occupied all space, the yield of grass per acre would have been approximately 2,250 pounds, compared with 1,747 pounds in pure stands. Thus, forage yield in the mixtures was higher than that in the grass, not only because of increased growth of grass but also because of the additional alfalfa.

Stand Depletion

It was evident in early spring of 1961, after an extremely dry 7-month period, that stands in the 80–N pastures were greatly reduced because many crested wheatgrass plants had died. In some locations enough plants had died to cause large bare areas of soil to appear. These were soon covered with *Kochia scoparia* (L.) Roth, a common weed easily controlled by spraying with common herbicides. In some cases the grass plants were not entirely dead but were dwarfed, with dead centers. Stands in adjacent 0–N pastures were not reduced, but stands in the 40–N pastures were reduced slightly. Seamands and Lang (*19*) found the same general tendency for stands of crested wheatgrass fertilized with high rates of nitrogen to thin out in certain years.

To determine if there were differences in electrical conductivity values or in soil pH, samples were taken of the 0- to 6-inch depth in areas of different degrees of stand depletion (stand index) in the various pastures. Almost without exception, conductivity values were higher and soil pH values lower in areas where plants had died or were weakened and the stand index was high (table 14). Neither the conductivity values nor pH was in the range considered toxic to plants (*24*). Conductivity values were so low that differences between treatments were of no significance other than to indicate the possibility of a concentration of nitrogen salts in certain areas.

The 80–N treatment could have caused increased respiration and carbohydrate utilization similar to those reported by a number of workers (*4, 7, 15*) with other cool-season grasses. In the present study, lowered root reserves in the 80–N pastures could have rendered the plants especially susceptible to drought and winter injury. Grazing pressure may have intensified the damage that resulted in stand depletion. Graber (*6*) in 1931 stated, "It is clearly evident that the productive capacity of grasses is not only dependent upon adequate supplies of available nutrients and moisture combined with favorable light and temperature conditions but also on food reserves of the plant. . . . When regeneration is constantly stimulated by fertile soil or by abundant nitrogenous fertilization the carbohydrate reserves are rapidly consumed and with slight opportunity for replenishment they often become the principal factors limiting growth."

The thin stands in the 80–N pastures in 1961 reduced production to approximately that of the 40–N pastures. However, in 1962, a favorable year for growth, production was higher in the 80–N pastures than in the 40–N pastures. Soil moisture samples in the spring showed a greater depth of moisture where stands were thin. From 1963

TABLE 14.—*Electrical conductivity and soil pH from the 0- to 6-inch depth from selected areas showing various degrees of stand depletion in crested wheatgrass pastures receiving various treatments, 1961*

Treatment	Conductivity EC x 10^3 at 25° C.[1]	Soil pH	Stand index [2]
80–N	0.60	5.55	5
80–N	.49	5.90	5
80–N	.42	5.60	5
80–N	.39	5.80	5
80–N	.37	5.60	4
80–N	.36	5.60	5
80–N	.33	6.05	2
40–N	.38	6.00	3
40–N	.30	5.95	3
0–N	.30	6.05	1
0–N	.28	6.00	1
0–N	.28	6.15	1
Mixture	.33	6.10	1
Mixture	.30	6.00	1

[1] Electrical conductivity of a saturated soil paste in millimho/centimeters (EC x 10^3).
[2] Stand index: 1 = no thinning of stand; 3 = medium thinning; 5 = severe thinning.

through 1965 vigor in the 80–N pastures decreased generally to a point below that in the 40–N pastures. Fertilization was discontinued in the fall of 1964, and relative vigor and yields of the 80–N pastures were regained by 1966 and 1967 and were again greater than those of the 40–N pastures.

Soil Water

Soil water samples were taken by 1-foot increments to a depth of 6 feet on four dates in 1958, on three in 1959, and on three in 1960 (table 15). Since there did not appear to be a significant relation between water use and forage and beef production per acre, sampling was discontinued in 1960. Soil water was approximately the same to a depth of 6 feet for all treatments in early spring each year. Soil was driest in the fall and increased in water content during the winter. When the October-March precipitation was added to the soil water in the fall, the loss in water from all treatments was much greater during the 1959–60 winter than during the 1958–59 winter. A partial explanation for this difference is that high precipitation after the last sampling date in 1958 increased the amount of soil water. In addition, late spring growth in 1959 reduced early water use. In 1959, high September-October precipitation resulted in fall regrowth, which reduced the soil water after the last sampling date.

Wide year-to-year variation in the soil water status of dryland soils is common. With the limited data available, we cannot draw definite conclusions. Differences between treatments were small and not statistically significant. The crested wheatgrass-alfalfa mixture did tend to-

TABLE 15.—*Total water in surface 6 feet of soil on 10 sampling dates under crested wheatgrass pastures receiving various treatments* [1 2]

Date	Water in soil under pastures treated with—			
	0–N	40–N	80–N	Mixture
	Inches	*Inches*	*Inches*	*Inches*
1958:				
April 8	11.80	12.16	12.78	12.12
May 18	10.63	10.05	10.23	10.03
June 24	11.65	11.24	11.74	10.99
October 8	9.81	9.49	9.66	9.35
1959:				
April 8	12.00	11.86	11.44	10.31
June 12	9.88	10.03	9.32	9.00
September 30	10.91	10.78	10.51	10.38
1960:				
April 12	11.29	11.09	11.39	10.77
June 29	11.25	10.58	11.16	10.75
September 22	9.70	9.52	9.33	9.31

[1] Soil water samples were taken by D. E. Smika, Soil and Water Conservation Research Division.

[2] The total water in the surface 6 feet of soil at 15 bars of tension was 9.42 inches.

ward greater water use, probably because of the presence of deeper rooted alfalfa. Water use under the unfertilized treatment appeared to be slightly less than that under the fertilized treatments, but the relative amount under the various treatments changed between dates.

Soil Changes

In general, the data consistently indicate that fertilization increased the organic carbon and total nitrogen content in the soil (table 16). The magnitude of the variation in individual soil samples between locations and depths (tables 20 to 23, appendix) was so great, however, that the amount of increase could not be statistically determined. Errors in analysis and in field samplings are normally greater than the differences found in total nitrogen between years and treatments.

Soil weight per acre-foot based on bulk density values for the 0- to 12-inch depth was 2,818,715 pounds and that for the 12- to 24-inch depth was 3,240,028 pounds. Pounds of organic carbon and total nitrogen for any treatment or depth can be calculated from the percent values shown in the data.

The data were not sufficient to determine the amount of nitrogen removed by the grass and the cattle. Based on forage yields and protein determinations, the amount of nitrogen used by the grass was approximately 277 pounds per acre in the 40–N treatment and approximately 374 in the 80–N treatment. Most of this was returned to the soil by excretions from the cattle while grazing. A determination of the amount lost by volatilization and the amount reincorporated in the soil

TABLE 16.—*Average percentage of organic carbon and total nitrogen and carbon/nitrogen ratio of soil under crested wheatgrass pastures receiving various treatments, 1954 and 1965*

Treatment and depth of soil (inches)	Organic carbon		Total nitrogen		Carbon/nitrogen ratio	
	1954	1965	1954	1965	1954	1965
	Percent	*Percent*	*Percent*	*Percent*		
0-N:						
0–6	2. 46	2. 44	0. 233	0. 235	10. 6	10. 4
6–12	1. 50	1. 66	. 160	. 168	9. 4	9. 9
12–24	. 88	1. 00	. 104	. 109	8. 5	9. 2
40-N:						
0–6	2. 49	2. 56	. 233	. 246	10. 7	10. 4
6–12	1. 58	1. 82	. 161	. 175	9. 8	10. 4
12–24	. 92	1. 06	. 103	. 112	8. 9	9. 5
80-N:						
0–6	2. 35	2. 66	. 229	. 245	10. 3	10. 9
6–12	1. 63	1. 64	. 147	. 165	11. 1	9. 9
12–24	. 94	1. 03	. 104	. 112	9. 0	9. 2
Mixture:						
0–6	2. 63	2. 72	. 243	. 245	10. 8	11. 1
6–12	1. 50	1. 72	. 157	. 167	9. 6	10. 3
12–24	1. 01	1. 07	. 108	. 111	9. 4	9. 6

was beyond the scope of this study. The amount of nitrogen removed in the bodies of the animals when taken from the pastures was probably negligible.

The pH values in soils 0 to 6 inches deep under the unfertilized pastures changed little, if at all; but the pH definitely tended to decrease in soils at this same depth under fertilized pastures (table 17.) Phosphorus was lost in all treatments, but the loss was least under fertilized pastures and greatest under the mixture. Individual soil samples showed varying degrees of loss in phosphorus between depths and locations (tables 20 to 23, appendix). The higher phosphorus content of the fertilized soils in 1965 was related to lowered pH. Increased acidity with nitrogen fertilization evidently resulted in the release of greater amounts of available phosphorus. The 1965 soil samples were taken in the fall after a season unusually favorable for high forage production accompanied by high phosphorus use. Possibly there had not been sufficient time for natural replenishment of available phosphorus to occur before samples were taken. The apparent 12-year loss might not have been as high if the samples in 1965 had been taken at a later date.

On the basis of work by Olsen and others (*14*), soils with less than 5.46 parts per million (p.p.m.) of sodium bicarbonate-soluble phosphorus ($NaHCO_3$-soluble P) should respond to phosphorus fertilization with increased crop production. On this basis, forage yields in the present study should have increased with phosphorus fertilization. However, fertilization of small plots in all pastures with 44 pounds of phosphorus per acre in 1963 did not increase forage yields that year (table 18). Possibly there had not been sufficient time for the phosphorus to become effective. Yields from the plots were not recorded in 1964 and 1965.

TABLE 17.—*Average values for pH and sodium bicarbonate-soluble phosphorus in 3 depths of soil under crested wheatgrass receiving various treatments, 1954 and 1965*

Treatment and depth of soil (inches)	pH		$NaHCO_3$-soluble P	
	1954	1965	1954	1965
			P.p.m.	*P.p.m.*
0-N:				
0–6	6. 0	5. 9	9. 36	4. 85
6–12	6. 2	5. 9	4. 14	2. 97
12–24	7. 0	6. 9	2. 78	2. 70
40-N:				
0–6	6. 0	5. 6	8. 60	5. 66
6–12	6. 3	6. 4	3. 92	3. 20
12–24	6. 9	6. 9	2. 82	2. 58
80-N:				
0–6	6. 2	5. 4	8. 66	7. 87
6–12	6. 4	6. 3	3. 20	3. 09
12–24	7. 1	7. 1	2. 68	2. 23
Mixture:				
0–6	6. 2	6. 0	9. 35	4. 48
6–12	6. 3	6. 1	4. 05	2. 87
12–24	6. 8	6. 9	3. 35	2. 45

TABLE 18.—*Average forage yields at hay stage in 1963 as influenced by one application of 44 pounds of phosphorus per acre on crested wheatgrass pastures receiving various treatments* [1]

Treatment	Forage yields after phosphorus treatment of—	
	0 pounds per acre	44 pounds per acre
	Pounds/acre	*Pounds/acre*
0–N	1, 387	1, 366
40–N	3, 170	3, 171
80–N	3, 800	3, 578
Mixture	2, 174	2, 006

[1] Phosphorus was surface applied as treble superphosphate on March 27, 1963.

SUMMARY

A 10-year study was conducted at the Northern Great Plains Research Center, Mandan, N. Dak., on pasture performance of crested wheatgrass fertilized annually with 40 and 80 pounds of nitrogen per acre as compared with pasture performance with no fertilization and with a crested wheatgrass-alfalfa mixture.

Average beef production for the 10 years was:

Treatment:	*Pounds per acre*
0–N	101
40–N	169
80–N	176
Mixture	135

Production from the 1st to the 10th year increased in the fertilized pastures, decreased slightly in the mixtures, and decreased sharply in the unfertilized pastures.

Daily gains of steers grazing on crested wheatgrass pastures were high (over 2.5 pounds), indicating the high nutritive quality of crested wheatgrass in the spring, but fertilization did not increase these daily gains. Increased beef production from fertilization was due to the increase in number of animals per unit of land and not to increased gains per head.

Carrying capacity of the 40–N pastures was 72 percent higher than that of the 0–N pastures and 37 percent higher than that of the mixtures. At the beginning of the study, carrying capacity of the 80–N pastures was higher than that of the 40–N pastures, but not at the end.

At the beginning of the grazing season, approximately 50 percent more forage was available for grazing on the fertilized pastures than on unfertilized. At the end of the grazing season, forage production from caged areas in the 80–N pastures increased 79 percent over that in the 0–N pastures; production in the 40–N pastures increased 59 percent, and production in the mixtures increased 29 percent.

Daily forage consumption per head was approximately 25 pounds, with no significant differences between treatments. The average forage requirement for the yearlings gaining 2.7 pounds per day was 9.9 pounds per pound of gain.

Forage yields at the end of the grazing season below and above a 2-inch clipping height indicated that little grazing had taken place below 2 inches. The major effect of fertilization was to increase the proportion of the yield above the 2-inch height.

Hay yields from protected areas were:

Treatment:	Yields *Tons/acre*	Average increase over 0–N treatment *Percent*
0–N	0.84	----------
40–N	1.52	81
80–N	1.63	94
Mixture	1.22	45

Residual effects in forage production from fertilization were pronounced 2 years after the last fertilization.

Nitrogen fertilizer increased the percentage of crude protein in the forage at all growth stages. Forage continuously grazed was higher in protein than forage protected by a cage.

TDN production determined by animal requirements was considered to be the best pasture measurement because both beef production per acre and steerdays of grazing were used in the calculations. TDN production for maintenance and gain were determined for all treatments. Total TDN production from the 40–N and 80–N treatments was not significantly different. The 40–N treatment produced 74 percent more TDN than the 0–N treatment and 29 percent more than the mixture. The mixture produced 35 percent more than the 0–N treatment. A highly significant positive relation of $r=0.95$ was determined between TDN and beef production per acre. TDN requirements per pound of beef were similar for all treatments and were not out of line with values determined by the National Research Council.

Steers on fertilized pastures tended to graze less uniformly than those on unfertilized pastures. Patchy grazing with overuse in local spots often occurred in the fertilized pastures.

Under a system of spring grazing only, alfalfa in the mixture increased from 10 percent in 1956 to 37 percent in 1965.

By the 6th year of production, losses in stands were noted in the 80–N pastures. Conductivity values tended to be higher and soil pH values were lower in areas where plants had died or were weakened. Neither value was in the range considered toxic to plants. It was assumed that stand depletion was due to lower root reserves and subsequent susceptibility to drought and grazing pressure. There was no stand depletion in the 40–N pastures.

Soil water samples indicated slightly higher water use by plants in the mixture than by plants in the other treatments. Differences in soil moisture between treatments were low and no definite soil moisture-pasture production relation was indicated.

Organic carbon and total nitrogen increased consistently with nitrogen fertilization, but differences in values between the beginning and end of the experiment were not significant because of the magnitude of the variation in sampling and analysis.

Soil pH tended to decrease in surface soils under the fertilized treatments. Phosphorus losses appeared to be less under the fertilized treatments and greatest under the mixture.

LITERATURE CITED

(1) Association of Official Agricultural Chemists.
1960. Official methods of analysis. Ed. 9. Washington, D.C.

(2) Bell, M. A., Reitz, L. P., and Tower, H. E.
1936. Crested wheatgrass in Montana. Mont. Agr. Expt. Sta. Bul. 323, 51 pp.

(3) Campbell, J. B.
1963. Grass-alfalfa versus grass-alone pastures grazed in a repeated-seasonal pattern. Jour. Range Mangt. 16: 78–81.

(4) Colby, W. G., Drake, M., Field, D. L., and Kreowski, G.
1965. Seasonal pattern of fructosan in orchardgrass stubble as influenced by nitrogen and harvest management. Agron. Jour. 57: 169–173.

(5) Duncan, D. B.
1955. Multiple range and multiple F tests. Biometrics 11: 1–42.

(6) Graber, L. F.
1931. Food reserves in relation to other factors limiting the growth of grasses. Plant Physiol. 6: 43–72.

(7) Hallock, D. L., Brown, R. H., and Blaser, R. E.
1965. Relative yield and composition of Ky. 31 fescue and coastal bermudagrass at four nitrogen levels. Agron. Jour. 57: 539–542.

(8) Jackman, E. R., Richards, D. E., and Stephens, D. E.
1936. Crested wheatgrass in eastern Oregon. Oreg. Ext. Bul. 494, 38 pp.

(9) Jackson, M. S.
1958. Soil chemical analysis. 498 pp., illus. Englewood Cliffs.

(10) Knowles, R. P.
1956. Crested wheatgrass. Canada Dept. Agr. Pub. 986, 13 pp.

(11) Lorenz, R. J., and Rogler, G. A.
1967. Nitrogen and 2,4-D increase crested wheatgrass production. N. Dak. Farm Res. 24: 13–16.

(12) Miller, R. V., Jr., and Terwilliger, C., Jr.
1961. Nitrogen fertilizer improves palatability of crested wheatgrass. Crops and Soils 13: 21.

(13) National Research Council.
1963. Nutrition requirements of beef cattle. Nat. Acad. Sci. Natl. Res. Council Pub. 1137, 30 pp.

(14) Olsen, S. R., Cole, C. V., Watanabe, F. S., and Dean, L. A.
1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. U.S. Dept. Agr. Cir. 939, 19 pp.

(15) Raese, J. T., and Decker, A. M.
1966. Yields, stand persistence, and carbohydrate reserves of perennial grasses as influenced by spring harvest stage, stubble height, and nitrogen fertilization. Agron. Jour. 58: 322–326.

(16) Rogler, G. A.
1944. Summer gains of yearling Hereford steers on native and cultivated pastures. N. Dak. Agr. Expt. Sta. Bimo. Bul. 6: 20–27.

(17) ———.
1960. Growing crested wheatgrass in the western states. U.S. Dept. Agr. Leaflet 469, 8 pp.

(18) ——— Lorenz, R. J., and Schaaf, H. M.
1962. Progress with grass. N. Dak. Agr. Expt. Sta. Bul. 439, 15 pp.

(19) Seamands, W., and Lang, R. L.
1960. Nitrogen fertilization of crested wheatgrass in southeastern Wyoming. Wyo. Agr. Expt. Sta. Bul. 364, 16 pp.

(20) Stitt, R. E., Hide, J. C., and Frahm, E.
1955. The response of crested wheatgrass and volunteer sweetclover to nitrogen and phosphorus under dryland conditions. Agron. Jour. 47: 568–572.

(21) SULLIVAN, J. T.
1964. THE CHEMICAL COMPOSITION OF FORAGES IN RELATION TO DIGESTIBILITY BY RUMINANTS. U.S. Dept. Agr., Agr. Res. Serv. ARS 34-62, 58 pp.

(22) SWIFT, R. W.
1957. THE CALORIC VALUE OF TDN. Jour. Animal Sci. 16: 753-756.

(23) THOMAS, J. R., and OSENBRUG, A.
1964. INTERRELATIONSHIPS OF NITROGEN, PHOSPHORUS, AND SEASONAL PRECIPITATION IN THE PRODUCTION OF BROMEGRASS-CRESTED WHEATGRASS HAY. U.S. Dept. Agr. Prod. Res. Rpt. 82, 27 pp.

(24) UNITED STATES SALINITY LABORATORY STAFF.
1954. DIAGNOSIS AND IMPROVEMENT OF SALINE AND ALKALI SOILS. U.S. Dept. Agr., Agr. Handb. 60, 160 pp.

(25) WHITMAN, W. C., LANGFORD, L., DOUGLAS, R. J., and CONLON, T. J.
1963. CRESTED WHEATGRASS AND CRESTED WHEATGRASS-ALFALFA PASTURES FOR EARLY-SEASON GRAZING. N. Dak. Agr. Expt. Sta. Bul. 442, 24 pp.

(26) WILLIAMS, R. M., and POST, A. H.
1945. DRY LAND PASTURE EXPERIMENTS. Mont. Agr. Expt. Sta. Bul. 431, 31 pp.

APPENDIX

TABLE 19.—*Yearly production of total digestible nutrients (TDN) based on yearling steer performance and TDN required per pound of gain from crested wheatgrass pastures receiving various treatments* [1]

Year and treatment	Steers per acre	Average weight per steer	Total weight of steers	TDN required daily per 100 pound weight for maintenance	Days grazed	TDN produced for maintenance	Total weight gain	TDN required per pound gain	TDN produced for gain	Total TDN produced	TDN required per pound of gain
	Number	*Pounds*	*Pounds/acre*	*Pounds*	*Number*	*Pounds/acre*	*Pounds/acre*	*Pounds*	*Pounds/acre*	*Pounds/acre*	*Pounds*
1956:											
0-N	1.47	579	851	0.677	45	259	173	2.40	415	674	3.90
40-N	1.75	571	999	.693	45	212	183	2.24	410	721	3.94
80-N	1.79	585	1,047	.677	45	319	244	2.40	586	905	3.71
Mixture	1.47	582	856	.677	45	261	187	2.40	449	710	3.79
1957:											
0-N	1.32	591	780	.677	35	185	107	2.40	256	441	4.13
40-N	1.69	607	1,026	.677	45	313	196	2.40	469	782	4.00
80-N	1.82	602	1,096	.677	45	334	202	2.40	484	818	4.06
Mixture	1.32	608	803	.677	35	190	153	2.40	366	557	3.65
1958:											
0-N	1.10	569	626	.693	30	130	97	2.24	217	347	3.58
40-N	1.69	576	973	.677	35	231	176	2.40	421	652	3.71
80-N	2.04	570	1,163	.693	35	282	191	2.24	428	710	3.72
Mixture	1.32	578	763	.677	35	181	139	2.40	333	514	3.70
1959:											
0-N	1.10	613	674	.677	25	114	82	2.40	197	311	3.79
40-N	1.75	612	1,071	.677	25	181	129	2.40	311	492	3.80
80-N	1.75	607	1,062	.677	25	180	111	2.40	267	447	4.02
Mixture	1.32	605	799	.677	25	135	78	2.40	187	322	4.14

1960:											
0-N	1.00	577	577	.677	40	156	100	2.40	239	396	3.97
40-N	1.49	576	858	.677	40	232	143	2.40	344	576	4.02
80-N	1.49	575	857	.677	40	232	144	2.40	346	578	4.01
Mixture	1.16	582	675	.677	40	183	123	2.40	295	478	3.89
1961:											
0-N	1.10	550	605	.693	25	105	66	2.24	147	252	3.84
40-N	1.54	555	855	.693	25	148	107	2.24	239	387	3.63
80-N	1.54	555	855	.693	25	148	109	2.24	243	391	3.60
Mixture	1.32	556	734	.693	25	127	94	2.24	210	337	3.60
1962:											
0-N	1.03	595	613	.677	45	187	108	2.40	260	447	4.12
40-N	1.64	595	976	.677	55	363	194	2.40	465	829	4.28
80-N	1.92	606	1,164	.677	55	433	192	2.40	461	895	4.66
Mixture	1.25	603	754	.677	45	230	162	2.40	389	618	3.82
1963:											
0-N	0.88	540	475	.693	30	99	71	2.24	158	257	3.64
40-N	1.47	552	811	.693	45	253	150	2.24	337	590	3.92
80-N	1.75	555	971	.693	45	303	187	2.24	419	722	3.86
Mixture	1.10	557	613	.693	45	191	126	2.24	283	474	3.76
1964:											
0-N	.88	565	497	.693	40	138	106	2.24	237	375	3.54
40-N	1.52	565	859	.693	45	268	174	2.24	389	657	3.78
80-N	1.52	557	847	.693	45	264	151	2.24	338	602	3.99
Mixture	1.10	561	617	.693	40	171	122	2.24	273	444	3.65
1965:											
0-N	.88	531	467	.693	40	130	98	2.24	220	349	3.56
40-N	1.75	545	954	.693	45	298	237	2.24	532	829	3.49
80-N	1.75	544	952	.693	45	297	232	2.24	521	817	3.51
Mixture	1.25	545	681	.693	45	212	172	2.24	385	597	3.48

[1] Animal requirements calculated from the National Research Council (*18*) equation $DE=74.5W^{0.75}(1+0.59\ g)$ where DE= digestible energy, W=weight of animal, and g=daily gain and assuming 2,000 kilocalories of DE per pound of TDN. All values are in terms of dry matter.

TABLE 29.—*Organic carbon, total nitrogen, pH, and sodium bicarbonate-soluble phosphorus of soils in 1954 and 1965 under crested wheatgrass pastures receiving no fertilizer (0–N)*

Replication No.	Location	Soil depth	Organic carbon		Total nitrogen		pH		$NaHCO_3$-soluble P	
			1954	1965	1954	1965	1954	1965	1954	1965
		Inches	*Percent*	*Percent*	*Percent*	*Percent*			*P.p.m.*	*P.p.m.*
I	East	0–6	2.21	2.11	0.203	0.210	5.9	5.8	8.28	4.16
I	West	0–6	2.52	2.58	.241	.248	6.0	5.8	9.89	5.94
II	East	0–6	2.55	2.46	.239	.235	6.1	5.9	7.87	4.28
II	West	0–6	2.66	2.64	.249	.247	6.0	5.9	11.41	5.81
Average			2.46	2.44	.233	.235	6.0	5.9	9.36	4.85
I	East	6–12	1.30	1.34	.142	.150	6.0	5.9	4.16	2.64
I	West	6–12	1.65	1.77	.174	.181	6.3	5.9	4.70	3.50
II	East	6–12	1.57	1.86	.169	.173	6.2	5.9	3.26	3.01
II	West	6–12	1.47	1.66	.153	.166	6.2	6.0	4.45	2.72
Average			1.50	1.66	.160	.168	6.2	5.9	4.14	2.97
I	East	12–24	.78	.80	.090	.094	7.0	7.1	2.47	3.38
I	West	12–24	.98	.96	.109	.112	7.1	7.0	3.01	2.72
II	East	12–24	1.03	1.20	.113	.122	6.9	6.7	2.64	2.22
II	West	12–24	.71	1.03	.102	.109	7.0	6.9	3.01	2.47
Average			.88	1.00	.104	.109	7.0	6.9	2.78	2.70

TABLE 21.—*Organic carbon, total nitrogen, pH, and sodium bicarbonate-soluble phosphorus of soils in 1954 and 1965 under crested wheatgrass pastures fertilized annually with 40 pounds of nitrogen per acre (40–N)*

Replication No.	Location	Soil depth	Organic carbon		Total nitrogen		pH		$NaHCO_3$-soluble P	
			1954	1965	1954	1965	1954	1965	1954	1965
		Inches	*Percent*	*Percent*	*Percent*	*Percent*			*P.p.m.*	*P.p.m.*
I	East	0–6	2.12	2.23	0.206	0.222	6.0	5.6	6.76	4.82
I	West	0–6	2.78	2.87	.261	.274	5.9	5.7	10.92	6.47
II	East	0–6	2.22	2.21	.208	.218	6.1	5.7	7.87	4.04
II	West	0–6	2.82	2.94	.257	.271	5.9	5.5	8.86	7.29
Average			2.49	2.56	.233	.246	6.0	5.6	8.60	5.66
I	East	6–12	1.27	1.39	.136	.144	6.3	6.4	3.26	2.64
I	West	6–12	1.84	2.11	.178	.195	6.1	6.2	4.58	3.92
II	East	6–12	1.38	1.60	.146	.159	6.5	6.1	3.26	2.72
II	West	6–12	1.83	2.17	.182	.203	6.1	6.9	4.58	3.50
Average			1.58	1.82	.161	.175	6.3	6.4	3.92	3.20
I	East	12–24	.73	.80	.086	.089	7.3	7.2	1.98	1.98
I	West	12–24	.99	1.10	.108	.120	6.8	7.2	3.01	2.47
II	East	12–24	.83	1.02	.098	.105	7.1	7.0	2.35	2.84
II	West	12–24	1.11	1.33	.118	.134	6.4	6.2	3.92	3.01
Average			.92	1.06	.103	.112	6.9	6.9	2.82	2.58

TABLE 22.—*Organic carbon, total nitrogen, pH, and sodium bicarbonate-soluble phosphorus of soils in 1954 and 1965 under crested wheatgrass pastures fertilized annually with 80 pounds of nitrogen per acre (80–N)*

Replication No.	Location	Soil depth	Organic carbon		Total nitrogen		pH		$NaHCO_3$-soluble P	
			1954	1965	1954	1965	1954	1965	1954	1965
		Inches	*Percent*	*Percent*	*Percent*	*Percent*			*P.p.m.*	*P.p.m.*
I	East	0–6	1. 61	2. 56	0. 217	0. 231	6. 1	5. 3	8. 16	8. 74
I	West	0–6	2. 37	2. 46	. 228	. 240	6. 4	5. 4	10. 18	8. 44
II	East	0–6	2. 75	2. 81	. 228	. 259	6. 1	5. 4	8. 00	7. 00
II	West	0–6	2. 66	2. 82	. 243	. 248	6. 0	5. 3	8. 28	7. 29
Average			2. 35	2. 66	. 229	. 245	6. 2	5. 4	8. 66	7. 87
I	East	6–12	2. 44	1. 74	. 163	. 176	6. 3	6. 3	3. 50	3. 38
I	West	6–12	1. 26	1. 54	. 129	. 157	6. 8	6. 7	3. 26	3. 62
II	East	6–12	1. 45	1. 75	. 145	. 172	6. 3	5. 9	3. 01	2. 64
II	West	6–12	1. 36	1. 53	. 149	. 156	6. 1	6. 1	3. 01	2. 72
Average			1. 63	1. 64	. 147	. 165	6. 4	6. 3	3. 20	3. 09
I	East	12–24	. 99	1. 03	. 111	. 115	6. 9	7. 1	3. 50	2. 35
I	West	12–24	. 88	. 90	. 102	. 100	7. 3	7. 2	2. 47	2. 22
II	East	12–24	. 90	1. 09	. 102	. 116	7. 1	7. 1	2. 10	1. 98
II	West	12–24	. 99	1. 08	. 110	. 117	6. 9	6. 9	2. 64	2. 35
Average			. 94	1. 03	. 104	. 112	7. 1	7. 1	2. 68	2. 23

TABLE 23.—*Organic carbon, total nitrogen, pH, and sodium bicarbonate-soluble phosphorus of soils in 1954 and 1965 under crested wheatgrass-alfalfa pastures*

Replication No.	Location	Soil depth	Organic carbon		Total nitrogen		pH		$NaHCO_3$-soluble P	
			1954	1965	1954	1965	1954	1965	1954	1965
		Inches	*Percent*	*Percent*	*Percent*	*Percent*			*P.p.m.*	*P.p.m.*
I	East	0–6	2. 19	2. 31	0. 213	0. 216	6. 5	5. 9	7. 70	3. 13
I	West	0–6	2. 55	2. 65	. 239	. 232	6. 1	5. 9	9. 60	4. 82
II	East	0–6	3. 19	3. 19	. 277	. 279	6. 0	6. 0	9. 60	4. 98
II	West	0–6	2. 60	2. 74	. 243	. 254	6. 0	6. 0	10. 50	4. 98
Average			2. 63	2. 72	. 243	. 245	6. 2	6. 0	9. 35	4. 48
I	East	6–12	1. 35	1. 56	. 139	. 148	6. 6	6. 8	3. 26	3. 13
I	West	6–12	1. 57	1. 78	. 177	. 182	6. 2	5. 9	5. 11	3. 13
II	East	6–12	1. 70	2. 03	. 168	. 191	6. 2	5. 9	3. 79	3. 01
II	West	6–12	1. 37	1. 51	. 142	. 147	6. 2	5. 9	4. 04	2. 22
Average			1. 50	1. 72	. 157	. 167	6. 3	6. 1	4. 05	2. 87
I	East	12–24	. 90	. 90	. 098	. 097	7. 1	7. 2	2. 84	2. 10
I	West	12–24	1. 07	1. 10	. 115	. 121	6. 4	6. 2	4. 58	2. 35
II	East	12–24	1. 15	1. 24	. 119	. 122	6. 6	6. 7	3. 50	2. 72
II	West	12–24	. 92	1. 03	. 098	. 102	6. 9	7. 3	2. 47	2. 64
Average			1. 01	1. 07	. 108	. 111	6. 8	6. 9	3. 35	2. 45

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