Crested Wheat Production:

Impacts on Fertility, Row Spacing, and Stand Age

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Impacts on Fertility, Row Spacing, and Stand Age

FORREST A. SNEVA and LARRY R. RITTENHOUSE

ABSTRACT

Impacts of nitrogen fertilizer (N), row spacing, and age of stand in the first 10 years of a crested wheatgrass stand were studied on a semi-arid soil. Sulfur (S), with and without N, was studied for two years. Spring and regrowth herbage yield, herbage mineral concentration and yield, and soil moisture depletion patterns were the principal components measured. Rates of N, frequency of N application, and row spacing interacted with years, which caused significant, complex, but interpretable second and third order interactions. However, 10-year mean yields were the same for row spacings of 6, 12, 24, and 36 inches and for annual versus biennial N applications. At the most efficient N rate (20 lb/ac), spring yields were increased 64 percent with little or no further impact on the regrowth after spring harvest. Adding S with N fertilization caused spring yield to double as compared with yields from unfertilized plots. Crude protein concentrations in the herbage increased with each increase of N applied, but with S in the presence of N this increase was not as large. The N-fertilized grasses depleted soil moisture more rapidly; however, with 20 lb/ac of N, soil moisture depletion rates did not always greatly differ from that of the controls.

SUMMARY

Crested wheatgrass was seeded in 6, 12, 24, and 36-inch rows on semi-arid rangeland in the spring of 1956. In the fall nitrogen (N) was surface applied at 0, 20, 30, 50, and 80 pounds per acre (lb/ac) annually and double these rates biennially. For 10 years spring herbage yield on May 15 and the subsequent regrowth on August 1 were sampled. Herbage crude protein (CP), phosphorus (P), calcium (Ca), potassium (K), sulfur (S), and dry matter (DM) concentrations were determined at the time of harvest. Soil moisture depletion under the various treatments was monitored from 1958 to 1960 at two soil depths. In 1971 and 1972, plot treatments were rearranged to compare the effects of N alone with N + S fertilizer. Spring, regrowth, and mature herbage yields were analyzed for N and S concentration. Soil samples were collected for some treatments and analyzed for N and S concentration.

Spring yield response varied with row spacing, years, level and frequency of applied N, with most variables strongly interacting with each other. Generally 20 lb/ac N was most efficient and increased the mean yield by 64 percent. The 10-year mean yield was the same for annual and biennial fertilizer applications and for different row spacings. Row spacings interacted with years, so that grasses in 6- and 12-inch rows produced the highest yield in the beginning years.

The 10-year mean regrowth yields were the same for all row spacings, with a mean yield increase of 23 percent at the 20 lb/ac N level. Mean regrowth yield was about 300 lb/ac but varied among years.

The CP concentrations of the spring herbage (May 15) increased as row spacing and N level increased and were greatest in herbage from plots fertilized biennially. Row spacing effects decreased with stand age, with the level and frequency of N interacting strongly with years upon the herbage CP concentration. The CP concentration in the regrowth was significantly influenced by years and the N level but not by the frequency of N application or by row spacing.

Concentrations of P, Ca, and S in the May 15 herbage increased at the higher levels of applied N and varied among years. Only the yield of S was significantly increased as the level of N fertilizer increased.

Herbage yield of grasses in 6- and 12-inch rows decreased after yield peaks in the second and third growth years. Nitrogen fertilizer, although maintaining a significantly higher yield level, did not offset the decreasing yield trend. Thus, our data supported the thesis that decreasing availability of soil N was not the major cause of decreasing yields as the stands aged.

Generally soil moisture depletion was most rapid under fertilized grass, but soil moisture depletion curves for the lowest N level were not always greatly different from that of unfertilized grasses. Row spacing effects on soil moisture depletion were small, and clipping to ground level on May 15 had no discernible influence on the subsequent soil moisture depletion rate.

Adding S with N alleviated the chlorotic conditions, significantly increased herbage yield, decreased the CP concentration in the May 15 herbage, increased the S concentrations, and decreased the N:S ratio in N-fertilized grass so that it equaled that of grasses on control plots.

INTRODUCTION

Grazing of seeded crested wheatgrass ranges has alleviated much of the undesirable early grazing pressure on native grass ranges in the semiarid West. Because of early spring flooding of meadow feeding grounds and frequent shortages of hay supplies, the need is still greater for earlier range forage in eastern Oregon than that currently provided by crested wheatgrass.

An earlier study (Sneva, Hyder, and Cooper, 1958) suggested that if plant density of crested wheatgrass stands could be increased, production response from N could provide for earlier grazing.

In this paper we report the results of a 10-year study to test that hypothesis and add to the general knowledge of N fertilization of crested wheatgrass in semi-arid communities. In addition, we present response of crested wheatgrass in two subsequent years from additions of S with and without N.

Study Site

The Squaw Butte Experiment Station is located in southeastern Oregon within the northern fringe of the Great Basin Province, at an elevation of 4,500 feet above sea level. It annually receives about 12 inches of precipitation, most of which is snow or rain during winter months, with about 25 percent received as rain during May and June.

The soils at the study site are unclassified but have been described by Eckert (1957) as a sandy loam overlying variable sandy clay loams 17 to 32 inches deep. The moisture equivalent of the A horizon varies from 15 to 26 percent, while that of the B_2 varies from 18 to 32 percent. Moisture concentration at 15 atmospheres of pressure was 6.9 to 11.6 percent for the A horizon, and 9.2 to 20.5 percent for the B_2.

MATERIALS AND METHODS

The study design was a two-way whole plot with three replications. Whole plot combinations were row spacings (RS) of 6, 12, 24, and 36 inches and rates (R) and frequencies of N applications across row spacings. The rates and frequencies of N were 0, 20, 30, 50, and 80 lb/ac applied annually and double these rates applied biennially (40, 60, 100, and 160 lb/ac).

Whole plots (10 x 108 ft.) were seeded with crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.) in the spring of 1956 with a single row, double disc, cone-type seeder. Ammonium nitrate was surface-applied to plots for treatments in the fall and annually or biennially thereafter.

Herbage was harvested from a 48 square foot area in each plot on May 15 (± 2 days) in each year (Y) beginning in 1957. Each plot was resampled about August 1 to estimate regrowth yield. Herbage was hand clipped to ground level. Herbage dry matter (DM) concentration was determined by immediately weighing the spring-harvested green herbage and reweighing after drying in a forced-air drier. Concentration of DM could not be determined in all years because of the presence of heavy dew or rain on leaf surfaces. Herbage yields herein are reported on an air-dry basis. Immediately after each sampling the treatment area surrounding the yield sample area was closely mowed.

The dry-yield samples were passed through a Wiley mill, subsampled, and stored in air-tight jars. Kjeldahl-N was determined for all spring-harvested samples (May 15) from 1958 to 1963 and for the regrowth in 1958, 1960, and 1961. In 1957, samples for Kjeldahl-N were composited by treatment. From 1961 to 1963 subsamples from 12-inch rows, fertilized with 0, 20, 50, and 80 lb/ac N, annually, were further analyzed for P, Ca, K, and S, while those in 1964 and 1965 were analyzed only for S. Chemical analyses were made according to Association of Official Agricultural Chemists (1965 ed.).

In the spring of 1957 soil moisture resistance blocks (plaster of paris), centered within plots and between rows, were placed 10 and about 26 inches below the soil surface in each plot of two replications. The 26-inch block was on or near the caliche layer underlying the soil. The blocks were read (1958-1960) with an electrical resistance meter at intervals beginning with the first observed new growth.

Row identity at 12-, 24-, and 36-inch spacing was maintained by hoeing volunteer grasses from between rows.

In the fall of 1970 and 1971, plots previously fertilized annually were fertilized at the same rates of N with ammonium nitrate; plots previously fertilized biennially were fertilized annually, at the annual N rates, with Ortho ANS[1] (ammonium nitrate plus 6% S–(N + S)).

Herbage yields from a 48 square foot area on half of each plot were determined on May 15 and August 1 in 1971 and 1972. Regrowth from areas sampled on May 15 was also sampled on August 1. Herbage samples were handled as described previously, and their Kjeldahl-N and S concentrations were determined for herbage from 12-inch row spacings fertilized annually with 0, 20, 50, and 80 lb/ac of N and N + S.

Soil samples from the surface 10 inches were taken at the time of spring harvest from 12-inch row spacings receiving 0, 20, 50, and 80 lb/ac of N and N+ S. Each sample consisted of three cores (0.75-in.) drawn from between rows. Samples were air dried, sealed in glass jars, and subsequently analyzed for N and S.

Statistical analysis was for two-way whole plot studies; however, because only one set of control plots was included, some analyses included only the applied N levels. Differences between means were tested with Duncan's multiple range test. Regression analyses were utilized to explore some relationships.

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[1] Use of a trade name does not imply its endorsement or approval of a product to the exclusion of other products that may also be suitable.

RESULTS

Crop year (July through June) precipitation for 1956 to 1972 is shown in Table 1. The precipitation mean of 11.7 inches for the period from 1956 to 1966 is close to the long-term normal. The 16.8 inches of precipitation in 1958, and the 5.8 inches in 1968 are the record high and low since official recording began in 1936.

Because of excellent moisture conditions during the first three years, the seeds on all plots germinated, became established, and developed excellent stands. Tumblemustard (*Sisymbrium altissimum*) and downy bromegrass (*Bromus tectorum*) were profusely present in the seeding year, with denser stands on the wider spaced rows and on fertilized plots. These species were eliminated by competition from the crested wheatgrass in 1957 and there were only trace amounts in succeeding years.

Volunteer seedlings of crested wheatgrass were sparsely scattered between established rows throughout the study, primarily between the 36-inch row spacings.

Spring yield. Herbage from unfertilized plots in the second growing season decreased significantly ($p < .05$) as RS increased (Figure 1). The next three years, yields from 6- and 12-inch row spacings were similar and both significantly ($p < .05$) greater than those from the 24-inch row spacings, which were significantly ($p < .05$) greater than those from the 36-

Table 1. Crop year (July-June) precipitation for the yield years 1956-1972

Yield year	Precipitation
	inches
1956	14.9
1957	14.0
1958	16.8
1959	6.8
1960	10.4
1961	8.1
1962	8.2
1963	13.6
1964	10.7
1965	15.0
1966	10.7
1967	12.3
1968	5.8
1969	13.5
1970	9.9
1971	11.8
1972	9.5
AVERAGE	11.3

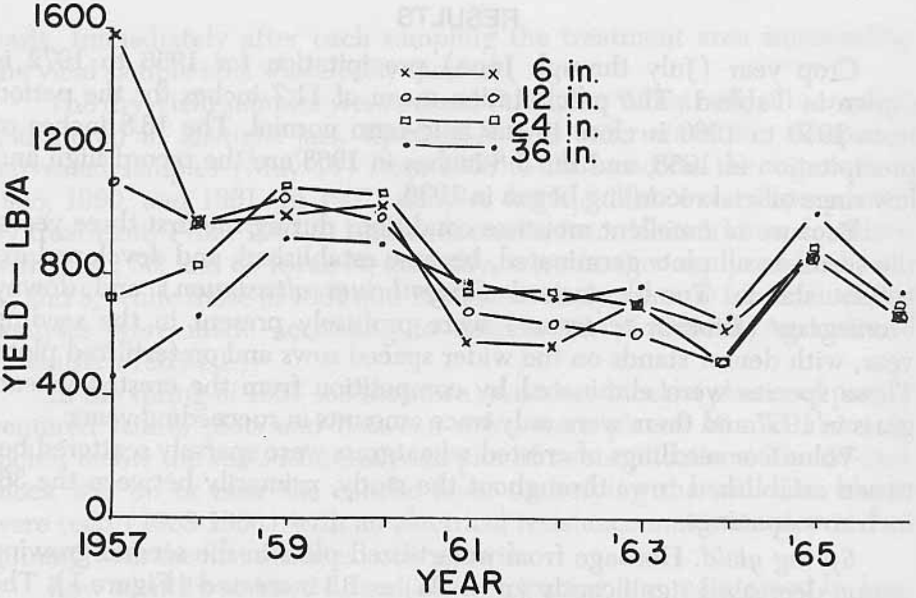

Figure 1. **Mean unfertilized crested wheatgrass yield on May 15 as influenced by row spacings of 6, 12, 24, and 36 inches.**

inch row spacings. Yield differences due to row spacing in the next four years (1961-1964) were small and nonsignificant; however, the trend was for greater yield from widely spaced than from narrowly spaced rows. Widely spaced rows significantly ($p < .05$) outproduced closely spaced rows in 1964, with nonsignificant yield differences ($p > .05$) due to row spacing in the last two years. The 10-year mean yields from unfertilized plots for 6, 12, 24, and 36-inch row spacings were 502, 515, 528, and 440 lb/ac, respectively, and did not differ from each other significantly ($p > .05$).

Nitrogen caused significant ($p < .05$) yield increases each year, with the lowest annual N rate (20 lb/ac) increasing the 10-year mean yield 64 percent above that of controls (zero N). Nitrogen rates above the lowest rate significantly ($p < .05$) increased yield in some years, while frequency of N applications also interacted with rate and year to cause significant ($p < .05$) yield differences. However, when we compared 10-year mean yields (Table 2) we noted the following: (1) yield differences between N rates applied annually were not significantly different; (2) yields of 60, 100, and 160 lb/ac N applied biennially did not differ from each other, but yields for 60 and 160 lb/ac were significantly greater than that of 40 lb/ac applied biennially; and (3) yield at the lowest level of N did not differ significantly ($p < .05$) with frequency of N application.

Table 2. Mean herbage yield of crested wheatgrass on May 15

N rate	Year[1]									
(lb/ac)	57	58	59	60	61	62	63	64	65	66	Mean
Annual											
0	672^{c}	631^{d}	592^{d}	518^{d}	498^{d}	487^{c}	374^{b}	358^{b}	471^{c}	367^{d}	497^{e}
20	908^{ab}	856^{b}	936^{c}	857^{c}	678^{bc}	755^{a}	777^{a}	620^{a}	1016^{ab}	738^{abc}	814^{bcd}
30	809^{bc}	824^{bc}	989^{abc}	1031^{abc}	698^{abc}	683^{ab}	701^{a}	619^{a}	926^{b}	668^{bc}	795^{cd}
50	933^{ab}	1016^{a}	1036^{bc}	1148^{a}	710^{abc}	738^{a}	688^{a}	554^{a}	949^{ab}	726^{abc}	850^{abcd}
80	1130^{a}	1082^{a}	996^{bc}	1199^{a}	604^{cd}	738^{a}	737^{a}	604^{a}	930^{b}	795^{ab}	882^{abc}
Biennial											
40	936^{ab}	689^{cd}	1042^{bc}	869^{bc}	786^{ab}	619^{b}	768^{a}	559^{a}	989^{ab}	609^{c}	785^{d}
60	1041^{ab}	778^{bc}	1250^{a}	1054^{ab}	813^{a}	711^{ab}	786^{a}	643^{a}	1065^{a}	767^{abc}	891^{ab}
100	1161^{a}	820^{bc}	1073^{bc}	1116^{a}	667^{bc}	659^{ab}	726^{a}	595^{a}	920^{b}	772^{ab}	851^{abcd}
160	1159^{a}	1084^{a}	1163^{ab}	1186^{a}	691^{bc}	718^{ab}	772^{a}	617^{a}	914^{b}	840^{a}	912^{a}
MEAN	972^{a}	862^{c}	1008^{a}	997^{a}	683^{d}	678^{d}	703^{d}	574^{e}	906^{bc}	698^{d}	808

[1] Means with unlike letters differ significantly ($p < .05$). Comparisons within the table are valid only within a column.

Second and third order interactions were significant ($p < .05$) because different production trends were established by the grasses in different row spacings; response differed to N within and between years, and between frequency of N applications.

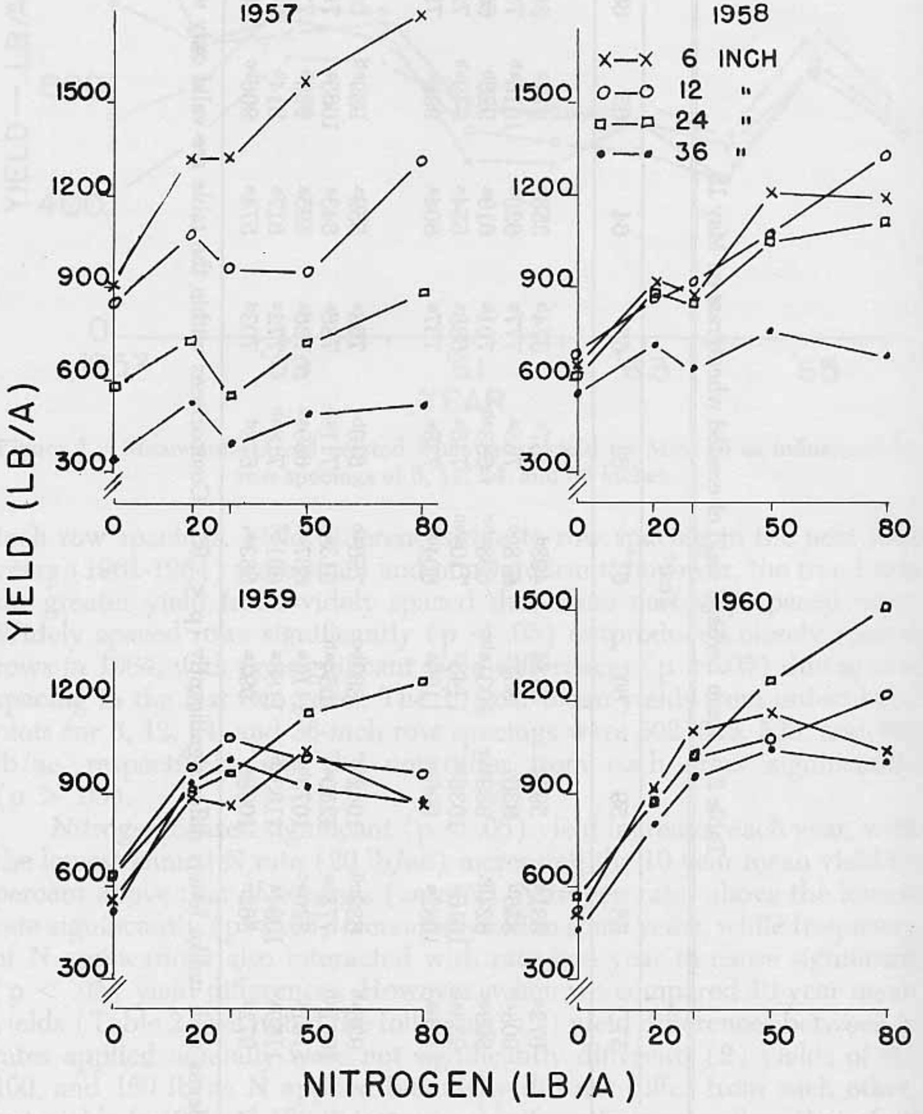

Figure 2. Mean crested wheatgrass yields on May 15 (1957 to 1960) as influenced by row spacing, nitrogen rates applied annually, and stand age.

The RS x N x Y interaction with the annual application of N is presented in Figures 2 and 3. In 1957, a near linear yield response to N developed for grasses in the 6-inch row spacing, the most productive spacing.

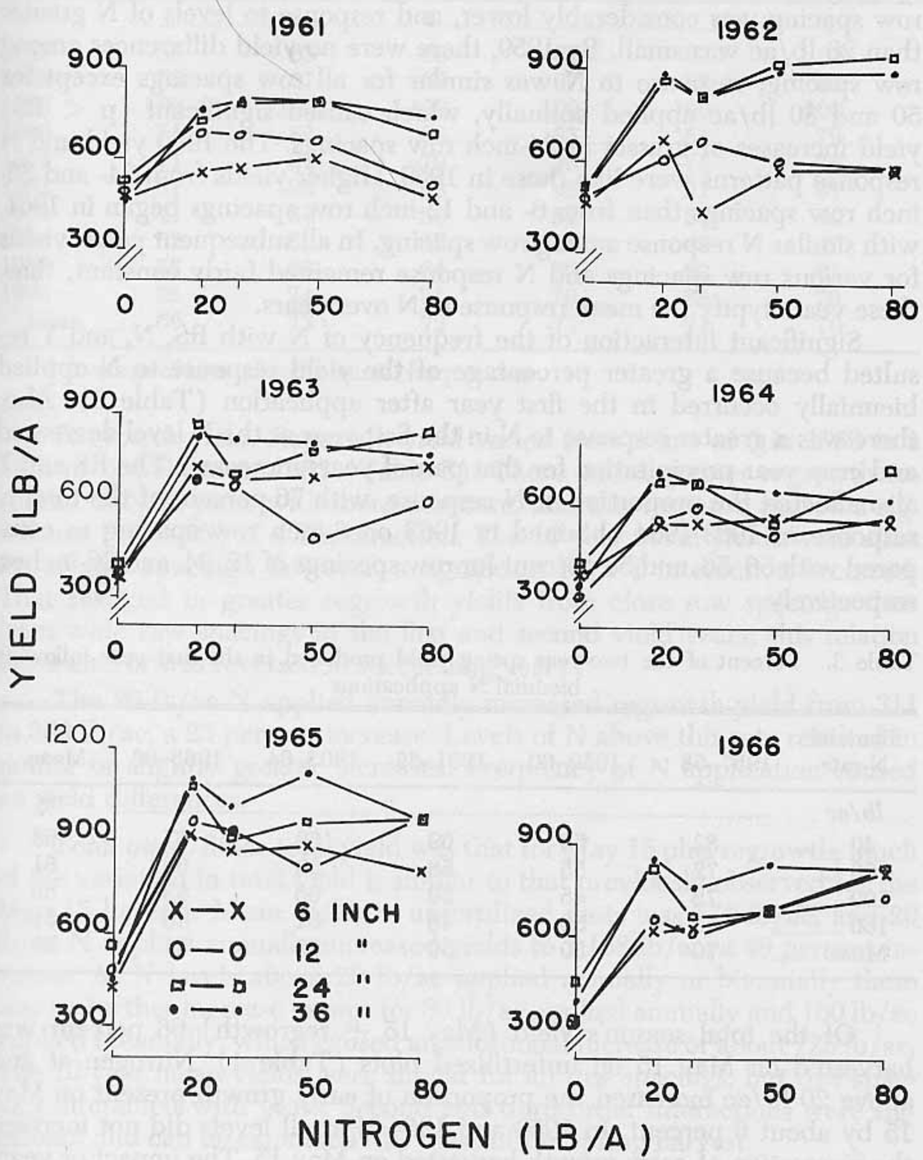

Figure 3. Mean crested wheatgrass yields on May 15 (1961 to 1966) as influenced by row spacing, nitrogen rates applied annually, and stand age.

In the wider row spacings response to N levels above 20 lb/ac was small, despite significantly ($p < .05$) greater yields as row spacing decreased. Response to N in 1958 was near linear for the 6-, 12-, and 24-inch row spacings with similar levels of production. Herbage yield at the 36-inch row spacing was considerably lower, and response to levels of N greater than 20 lb/ac was small. By 1959, there were no yield differences among row spacing; response to N was similar for all row spacings except for 50 and 80 lb/ac applied annually, which caused significant ($p < .05$) yield increases of grasses in 24-inch row spacings. The 1960 yield and N response patterns were like those in 1959. Higher yields from 24- and 36-inch row spacings than from 6- and 12-inch row spacings began in 1961, with similar N response among row spacing. In all subsequent years, yields for various row spacings and N response remained fairly constant; thus, these years typify the mean response to N over years.

Significant interaction of the frequency of N with RS, N, and Y resulted because a greater percentage of the yield response to N applied biennially occurred in the first year after application (Table 3). Also, there was a greater response to N in the first year as the N level decreased and crop year precipitation for that pair of years increased. The RS and Y also affected the proportion of N response, with 76 percent of the total N response in 1963-1964 obtained in 1963 on 6-inch row spacing as compared with 56, 56, and 58 percent for row spacings of 12, 24, and 36-inches, respectively.

Table 3. Percent of the two-year spring yield produced in the first year following biennial N applications

Biennial N-rate	1957–58	1959–60	1961–62	1963–64	1965–66	Mean
lb/ac			%			%
40	82	56	69	69	67	68
60	72	55	58	59	60	61
100	72	45	50	60	53	56
160	53	50	46	61	48	51
MEAN	70	50	56	62	57	59

Of the total season's yield (May 15 + regrowth) 66 percent was harvested on May 15 on unfertilized plots (Table 4). Nitrogen at and above 20 lb/ac increased the proportion of early growth present on May 15 by about 6 percent. In 1959 and 1964 N at all levels did not increase the proportion of early growth harvested on May 15. The impact of years upon the proportion of yield present on May 15 was large, with as much as 100 percent in the drought year of 1959, and as little as 47 percent in 1964.

Table 4. Percent of total crested wheatgrass yield present on May 15

	N (lb/ac)[1]					
Year	0	20	30	50	80	Mean
			%			%
1957	58	63	63	66	67	63
1958	58	67	67	67	68	65
1959	100	100	100	100	100	100
1960	71	82	83	83	84	79
1961	71	81	79	78	74	78
1962	87	93	93	93	91	91
1963	41	54	50	51	54	50
1964	53	50	47	42	45	47
1965	55	66	64	60	60	61
1966	65	74	71	70	68	70
Mean	66	73	72	71	71	70

[1] Average of annual and biennial frequencies.

Regrowth yield. Regrowth yield varied from a low of 0 in 1959 to a high of 666 lb/ac in 1963 (Table 5). There was a greater regrowth response to N in years with more moisture, and this response caused a significant ($p < .05$) N x Y interaction. The 10-year mean yields were alike for all row spacings; however, a significant RS x Y interaction occurred. That resulted in greater regrowth yields from close row spacings than from wide row spacings in the first and second yield years; this relation decreased or was reversed in succeeding years.

The 20 lb/ac N applied annually increased regrowth yield from 311 to 383 lb/ac, a 23 percent increase. Levels of N above this rate resulted in similar or slightly greater increases. Frequency of N application caused no yield differences.

Total yield. Since total yield was that for May 15 plus regrowth, much of the variation in total yield is similar to that previously observed for the May 15 harvest. Mean yield on unfertilized plots was 776 lb/ac, and 20 lb/ac N applied annually increased yields to 1,158 lb/ac, a 49 percent increase. At N levels above 20 lb/ac applied annually or biennially there was no further increase except for 80 lb/ac applied annually and 160 lb/ac applied biennially, which caused an additional increase of about 125 lb/ac. The 10-year mean yields were similar for all row spacings, but row spacings interacted with years. Second and third order interactions were significant and can be explained like those of the spring harvest.

Yield trend. The May 15 and total yield of grasses at 6- and 12-inch row spacings, with and without N, decreased as the stand aged. The mag-

Table 5. Mean regrowth yields on August 1 from plots harvested May 15 as influenced by years, row spacing, nitrogen rate, and frequency of nitrogen application

Row space (inches)	Years										
	57	58	59	60	61	62	63	64	65	66	Mean
						lb/ac					
6	603^{a}	412^{a}	0	163^{b}	185^{a}	0^{b}	656^{a}	635^{b}	535^{b}	300^{a}	388^{a}
12	658^{a}	418^{a}	0	231^{a}	167^{a}	83^{a}	653^{a}	598^{b}	510^{b}	277^{a}	399^{a}
24	481^{b}	538^{a}	0	268^{a}	204^{a}	75^{a}	744^{a}	625^{b}	532^{b}	255^{a}	413^{a}
36	327^{c}	462^{a}	0	251^{a}	192^{a}	81^{a}	611^{a}	701^{a}	631^{a}	274^{a}	392^{a}
						Nitrogen (lb/ac)					
Annual											
0	479^{a}	452^{ab}	0	213^{bc}	146^{e}	77^{a}	534^{d}	318^{e}	379^{c}	199^{e}	311^{g}
20	541^{a}	426^{b}	0	188^{c}	161^{de}	55^{ab}	667^{bc}	631^{c}	519^{b}	254^{d}	383^{ef}
30	484^{a}	402^{b}	0	209^{bc}	181^{bcd}	53^{ab}	702^{abc}	700^{ab}	529^{b}	277^{cd}	393^{de}
50	490^{a}	497^{ab}	0	238^{bc}	206^{abc}	58^{ab}	665^{bc}	761^{a}	622^{a}	316^{bc}	428^{abc}
80	536^{a}	512^{ab}	0	226^{bc}	213^{ab}	73^{ab}	640^{c}	734^{a}	627^{a}	375^{a}	437^{ab}
Biennial											
40	501^{a}	404^{b}	0	212^{bc}	176^{cde}	52^{ab}	753^{a}	517^{d}	432^{c}	185^{e}	359^{f}
60	547^{a}	461^{ab}	0	227^{bc}	185^{abcd}	46^{b}	725^{ab}	644^{bc}	563^{ba}	263^{d}	407^{cde}
100	522^{a}	403^{b}	0	242^{b}	199^{abc}	52^{ab}	656^{bc}	727^{a}	654^{a}	287^{cd}	416^{bcd}
160	559^{a}	560^{a}	0	300^{a}	217^{a}	71^{ab}	651^{bc}	728^{a}	639^{a}	332^{ab}	451^{a}
MEAN	517^{b}	458^{c}	0	228^{de}	187^{e}	60^{f}	666^{a}	640^{a}	552^{b}	276^{d}	398

Statistical significance at $P < .05$ is noted by unlike superscripts. Comparisons inside the table are valid for columns only.

nitude of this decrease is presented in Figure 4 for the 6-inch rows only. Regression analyses of the log transformed yield for row spacings of 6 and 12 inches at 0 and 20 lb/ac N applied annually resulted in significant ($p < .05$) negative regression coefficients; however, the regression coefficients between unfertilized and fertilized treatments were not significantly different ($p > .05$).

Herbage crude protein concentrations. The CP percentage increased in the herbage as row spacing increased for the first three years (Table 6). This pattern decreased in the fourth year, and in subsequent years was unaffected by row spacing. This caused a significant RS x Y interaction, but the mean CP percentage for the five years included in the analyses was not significantly different for row spacing.

Each higher N level applied annually caused a significant increase in CP: 12.6, 14.7, 16.7, 19.1, and 20.9 percent, respectively. Comparable lev-

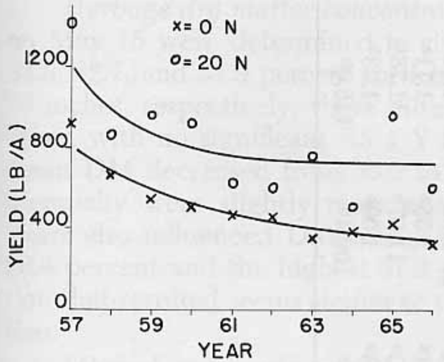

Figure 4. May 15 yield trend of crested wheatgrass fertilized with 20 lb/ac N annually and unfertilized crested wheatgrass growing in 6-inch rows.

els of N applied biennially generally caused slightly higher CP (about 0.3 percentage unit).

In the first year after the biennial application, CP was 0.8 percent higher than in years with comparable annual N levels, while in the residual response year, CP from biennial applications was 0.3 percent lower than that from annual applications. The CP increased more from N applied in the drier years than from that in wet years, which caused a significant N x Y interaction. The CP concentrations were significantly ($p < .05$) related to mean April temperature ($r = -0.781$).

In regrowth, the percent of CP was determined in four different years with no difference due to RS or frequency of N application, while years and rates caused significant differences ($p < .05$). Unfertilized grass contained 8 percent CP, with 20, 30, 50, and 80 lb/ac N annually increasing the CP to 9.0, 9.5, 11.1, and 12.5 percent, respectively. Mean concentrations for years ranged from 5.8 to 12.1 percent.

Table 6. Herbage crude protein concentration on May 15 as influenced by row spacings (averaged across N rate and frequency of N application)

Row space	Crude protein concentration[1]							
	1957[2]	1958	1959[2]	1960	1961	1962	1963	Mean
	%							
6	12.6	13.4^{b}	15.6^{ab}	13.7^{b}	17.4^{a}	16.1^{a}	24.7^{a}	17.1^{a}
12	15.6	14.3^{b}	15.5^{b}	14.5^{ab}	17.0^{a}	16.1^{a}	24.7^{a}	17.3^{a}
24	17.2	15.9^{a}	15.8^{ab}	14.5^{ab}	17.1^{a}	15.1^{a}	24.8^{a}	17.5^{a}
36	17.7	16.7^{a}	16.8^{a}	15.5^{a}	17.5^{a}	15.2^{a}	24.5^{a}	17.9^{a}

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[1] Means with unlike letters differ significantly ($p < .05$). Comparisons within the table are valid only within a column.

[2] 1957 values are of composite samples; 1959 data inadvertently left out of machine analysis. Neither year's data are included in outside means.

Table 7. Three-year (1961 to 1963) mean mineral concentrations and yields of crested wheatgrass herbage (grown in 12-inch rows and harvested on May 15)

	Nitrogen (lb/ac annually)[1]							
Constituent	0	20	50	80	0	20	50	80
	%				*lb/ac*			
Phosphorus	0.184^{a}	0.193^{ab}	0.196^{b}	0.206^{c}	0.72^{a}	1.24^{a}	0.99^{a}	1.10^{a}
Calcium	0.257^{a}	0.240^{a}	0.290^{b}	0.327^{c}	1.04^{a}	1.51^{a}	1.55^{a}	1.71^{a}
Potassium	1.98^{a}	1.99^{a}	2.10^{a}	2.24^{a}	7.96^{a}	12.50^{a}	11.07^{a}	11.78^{a}
Sulfur	0.22^{a}	0.22^{a}	0.21^{a}	0.25^{b}	0.88^{a}	1.36^{b}	1.09^{b}	1.23^{b}
Crude protein	12.2^{a}	16.0^{b}	21.7^{c}	22.4^{d}	49.2^{a}	100.7^{b}	109.4^{b}	118.0^{b}

[1] Means within a row with unlike letters differ significantly ($p < .05$).

Herbage dry matter concentrations. The herbage DM concentrations on May 15 were determined in six different years. Mean DM was 36.2, 33.8, 32.7, and 31.9 percent for herbage at row spacings of 6, 12, 24, and 36 inches, respectively; these differed significantly ($p < .05$) from each other, with no significant RS x Y interaction. As N levels increased, the mean DM decreased from 35.5 to 31.2 percent, and levels of N applied biennially were slightly more effective than annual applications of N. Years also influenced DM concentrations, with the lowest year mean at 26.4 percent and the highest 37.2 percent. The significant N x Y interaction that resulted seems similar to that same interaction for CP concentration.

Mineral and crude protein constituents. In 1961, 1962, and 1963 the May 15 herbage concentrations of P, Ca, S, and CP significantly ($p < .05$) increased at the following rates of N: P, 50 and 80 lb/ac; Ca, 50 and 80 lb/ac; S, 80 lb/ac; CP, 20, 50, and 80 lb/ac (Table 7). Yields of all constituents tended to increase as N level increased, but only S and CP increased significantly ($p < .05$).

The P concentrations differed significantly ($p < .05$) each year, but P yield was significantly greater in 1963 (Table 8). The Ca concentration was significantly ($p < .05$) higher in 1962 than in the two other years, but the yield in 1962 differed significantly only from that in 1963. Years had little effect on K concentrations, with the 1963 yield significantly ($p < .05$) less than in the previous two years. Neither concentration nor yield of S was influenced by years. The CP concentration was highest in 1963, as was its yield.

Table 8. Mean concentrations and yields of mineral in crested wheatgrass herbage (grown in 12-inch rows and harvested on May 15)[1]

	Years[2]					
Constituent	1961	1962	1963	1961	1962	1963
		%			lb/ac	
Phosphorus	0.156^a	0.142^b	0.287^c	0.89^a	0.76^a	1.36^b
Calcium	0.277^a	0.316^b	0.240^a	1.56^a	1.66^a	1.13^b
Potassium	1.99^a	2.18^a	2.07^a	11.13^a	11.48^a	9.87^b
Sulfur	0.22^a	0.22^a	0.22^a	1.22^a	1.13^a	1.06^a
Crude protein	15.6^a	15.6^a	23.0^b	88.2^a	83.8^a	111.0^b

[1] Fertilized annually with 0, 20, 50, and 80 lb/ac N.

[2] Means within a row with unlike letters differ significantly ($p < .05$).

Nitrogen efficiency. On May 15, the highest N efficiency (18.7 lb herbage/lb N) resulted from 6-inch row spacing fertilized with 100 lb/ac applied biennially (Table 9). Grasses in 36-inch rows and fertilized with

Table 9. Ten-year mean estimates of nitrogen efficiency[1] for the May 15 harvest and for total yield (May 15 yield plus regrowth)

Row space (in.)	Fertilizer rate								
	Annual				Biennial				
	20	30	50	80	40	60	100	160	Avg.
					lbs additional herbage/lb N				
May 15 yields									
6	15.4	9.7	7.9	4.7	16.8	15.1	18.7	7.0	11.9
12	14.0	9.9	5.4	4.5	14.0	11.8	6.6	5.2	8.9
24	15.8	8.7	7.1	5.6	10.4	12.8	6.0	4.1	8.8
36	18.4	11.5	7.9	4.4	16.5	12.8	7.1	4.6	10.4
Avg.	15.9	10.0	7.1	4.8	14.4	13.1	9.6	5.2	10.0
Total yield									
6	18.5	11.9	9.9	5.9	19.6	18.4	10.7	8.7	13.0
12	16.0	11.8	7.2	6.1	15.2	14.8	8.5	6.4	10.8
24	20.4	11.5	9.3	7.4	12.1	15.5	7.5	5.7	11.2
36	21.5	14.4	10.3	5.6	19.4	15.3	9.2	6.2	12.7
Avg.	19.1	12.4	9.2	6.2	16.6	16.0	9.0	6.8	11.9

[1] Pounds of additional herbage per pound of nitrogen applied.

20 lb/ac N annually were slightly less efficient (18.4 lb herbage/lb N). Biennial applications at the lowest N level averaged 9 percent less efficient than the comparable annual N rate. At higher rates, the biennial application was more efficient, but overall N efficiency at the higher rates of N was low for both application frequencies.

Nitrogen efficiency was greatest for total yield and highest efficiency (21.5 lb herbage/lb N) was obtained at the 36-inch row spacing with the lowest annual N rate. Nitrogen efficiency for that rate with the closer row spacing was about 14 percent less. Biennial applications of the lowest N rate on 6- and 36-inch row spacings were almost as efficient as the most efficient annual application (19.6 and 19.4 lb herbage/lb N vs. 21.5 lb herbage/lb N). Biennial applications were more efficient than annual applications as the level of N increased. The 6-inch row spacings were generally most efficient, with N efficiency decreasing for intermediate spacings and increasing for the widest row spacing.

Soil moisture. Figures 5 and 6 show soil moisture depletion curves for 1958 to 1960 at the 10- and 26-inch depths. These years represent a high and a low precipitation year. Curves are presented only for unfertilized, 20 and 80 lb/ac N annually, and 160 lb/ac N biennially, since these levels present the range in soil moisture depletion.

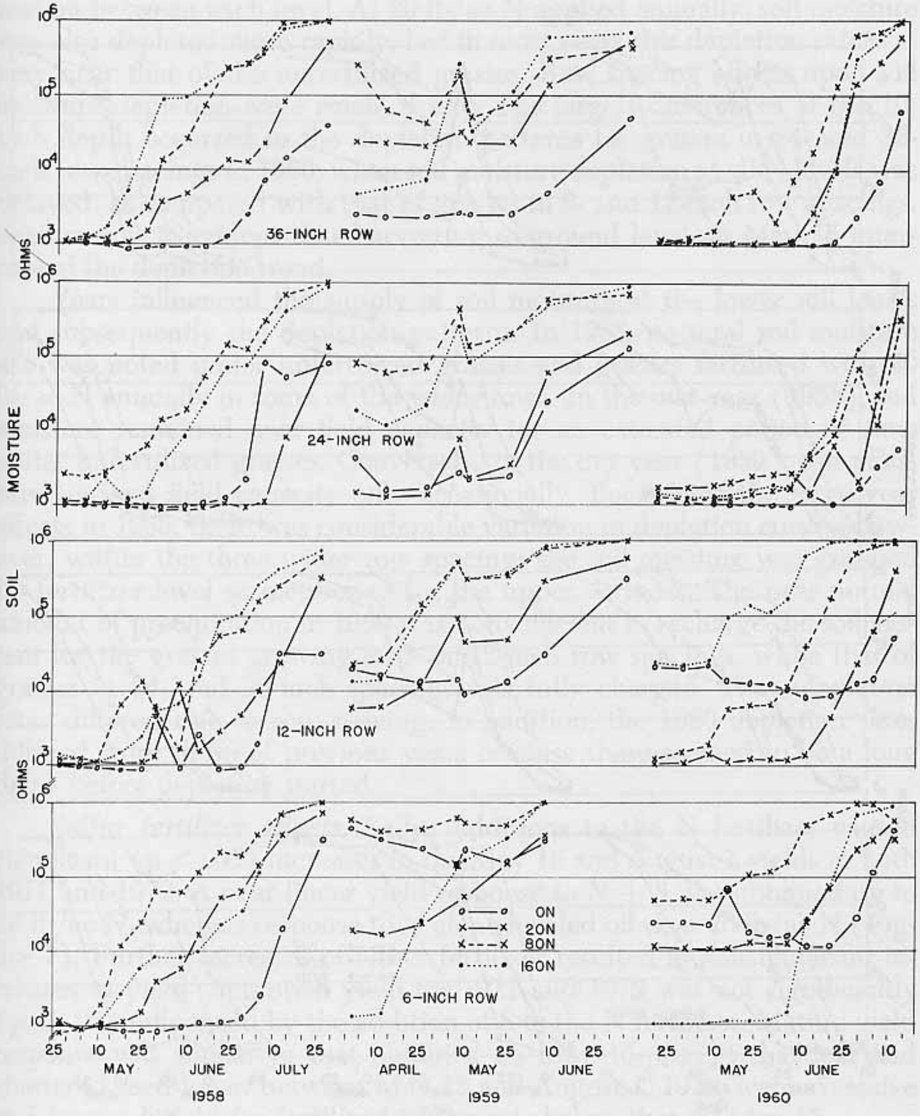

Figure 5. Soil moisture at 10-inch depth under unfertilized crested wheatgrass and at 20 and 80 lb/ac N annually and 160 lb/ac N biennially in 6-, 12-, 24-, and 36-inch rows.

Soil moisture in the upper soil surface equaled or exceeded field capacity (about 0.5 atm or 10^3 ohms) in the early spring of each year. By May 15 the grasses fertilized at 80 lb/ac N annually or 160 lb/ac N biennially had affected soil moisture depletion so that in 1959, soil moisture

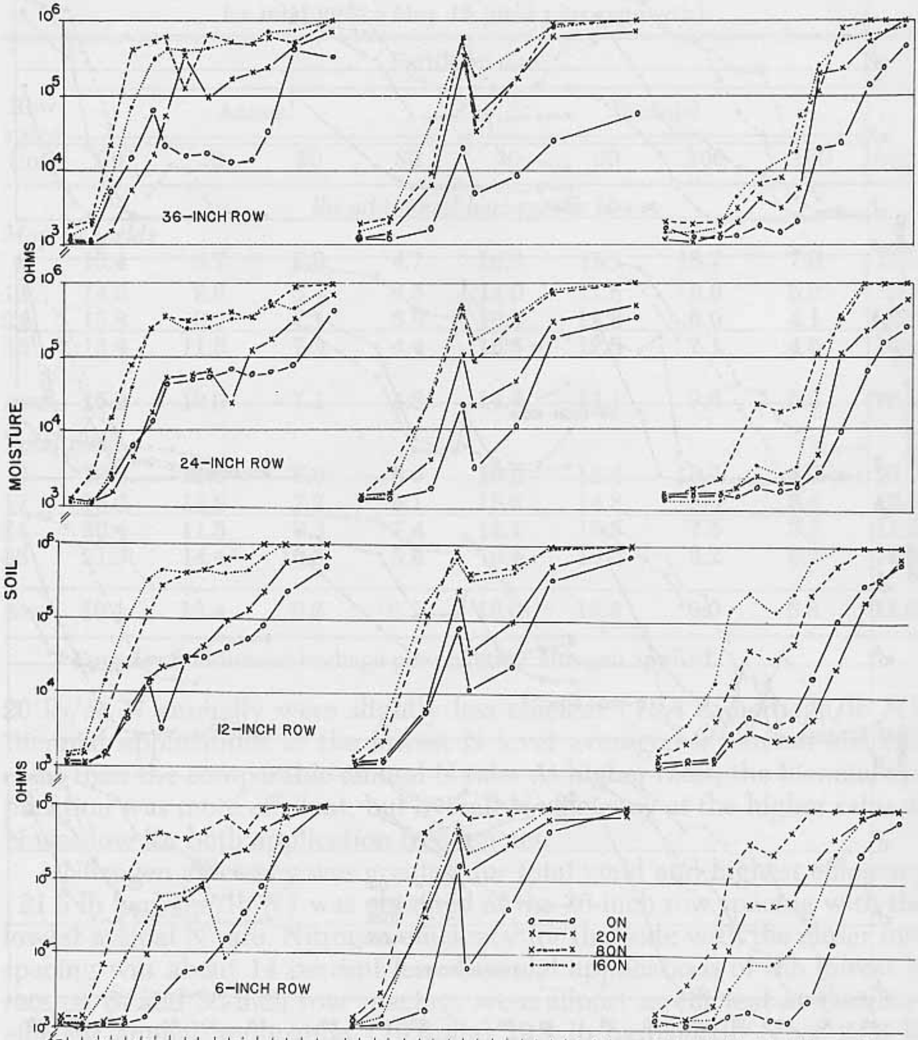

Figure 6. Soil moisture at 26-inch depth under unfertilized crested wheatgrass and at 20 and 80 lb/ac N annually and 160 lb/ac N biennially in 6-, 12-, 24-, and 36-inch rows.

was approaching or below the wilting range (about 31 atm or $10^{5.5}$ ohms). Depletion rates for grasses fertilized at the two highest N rates were similar, except at the 6-inch row spacing, where N levels caused greater separation between each level. At 20 lb/ac N applied annually, soil moisture was also depleted more rapidly, but in most years this depletion rate was very near that of the unfertilized grasses. Row spacing effects upon soil moisture depletion were small, if any. The largest differences at the 10-inch depth occurred in the depletion patterns for grasses in 24- and 36-inch row spacings in 1960, when soil moisture depletion at all N levels was delayed, as compared with that of grasses in 6- and 12-inch row spacings. Seldom was it evident that harvesting to ground level on May 15 interrupted the depletion trend.

Years influenced the supply of soil moisture at the lower soil levels and subsequently the depletion patterns. In 1958, no total soil moisture use was noted under unfertilized grasses and grasses fertilized with 20 lb/ac N annually in some of the wider rows. In the wet year (1958), soil moisture remained near field capacity for an extended period of time under unfertilized grasses. Conversely, in the dry year (1959), soil moisture reached field capacity only occasionally. Because of the large year effects in 1959, there was considerable variation in depletion curves; however, within the three wider row spacings the soil moisture was grouped by fertilizer level as mentioned for the upper surfaces. The near normal amount of precipitation in 1960 was not sufficient to recharge the soil system for the grasses growing in 6- or 12-inch row spacings, while that of grasses in 24- and 36-inch spacings was fully charged. Thus, depletion rates differed due to row spacing; in addition, the 1960 depletion rates differed from those of previous years because there seemed to be a long delay before depletion started.

Sulfur fertilizer effects. Sulfur additions to the N fertilizer caused significant ($p < .05$) increases in the May 15 and August 1 yields in both 1971 and 1972. A near linear yield response to N + S was obtained up to 30 lb/ac N, whereas response to N alone leveled off near 20 lb/ac N (Figure 7). Further increases of either fertilizer resulted in nonsignificant increases in yield. Regrowth yield for 1971 and 1972 was not significantly ($p < .05$) influenced by the addition of S to the N fertilizer. Mature yield response was similar to that obtained on May 15, except that leaf and shattered seed losses between May 15 and August 1, 1972, were excessive and lowered yield for fertilized treatments below that on May 15.

Table 10 shows that herbage concentrations of N on May 15 were increased significantly with N fertilizer in both 1971 and 1972, while concentration was less in the presence of N + S (significantly so in 1972). Sulfur concentrations increased significantly in both years with N alone and with N + S. Only in 1972 was the level of N x fertilizer source interaction significant ($p < .05$), and this was caused by line slope differences. The N:S ratio was increased with all N rates, but differences between N

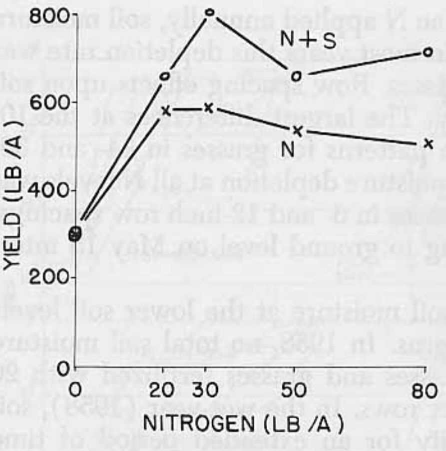

Figure 7. Two-year mean crested wheatgrass yield as influenced by nitrogen plus sulfur (N + S).

fertilizer rates were not significant ($p < .05$) (Table 10). Adding S significantly decreased N:S ratios below that of N fertilizer alone, giving ratios similar to that of controls.

The S and N concentrations in mature herbage were less than those of May 15 herbage (Table 10). Nitrogen, but not S, concentrations differed significantly ($p < .05$) among N rates. Sulfur concentrations, but not N, were increased with S added to the N fertilizer. In mature herbage, N:S ratios increased with increasing level of N fertilization, with significant differences ($p < .05$) occurring between 20 and 50 lb/ac N. Significantly

Table 10. Nitrogen and sulfur concentrations and nitrogen:sulfur ratios in crested wheatgrass herbage

Sample date		N (lb/ac)				Fertilizer	
		0	20	50	80	N	N + S
1971							
May 15[1]	N percent	3.08	3.18^a	4.23^b	4.20^b	4.15^a	3.68^a
	S percent	0.200	0.223^a	0.306^b	0.295^b	0.222^a	$.332^a$
	N:S[2]	10.4	14.9^a	14.9^a	14.6^a	18.8^a	11.2^b
August 1	N percent	0.70	1.10^a	1.62^b	1.94^b	1.60^a	1.51^a
	S percent	0.126	0.156^a	0.171^a	0.184^a	0.146^a	0.197^b
	N:S[2]	10.5	7.1^a	9.5^b	11.0^b	10.9^a	7.5^b
1972							
May 15	N percent	1.61	2.00^a	2.80^b	2.92^b	2.77^a	2.37^b
	S percent	0.230	0.206^a	0.246^b	0.281^c	0.217^a	0.271^b
	N:S[2]	7.0	9.7^a	11.6^a	10.6^a	12.6^a	8.7^b

[1] Row means with unlike letters differ significantly ($p < .05$).
[2] Retranslated means derived from arcsin transformations.

($p < .05$) lower N:S ratios were present in mature herbage fertilized with N + S than in herbage fertilized with N alone.

Herbage samples retained from May 15 (1961 to 1965) 12-inch row spacings unfertilized and fertilized annually with 20, 50, and 80 lb/ac N were analyzed and the N:S ratios determined. Mean ratios were 8.3, 9.7, 12.5, and 13.6 with S concentrations of 0.22, 0.22, 0.23, and 0.23 percent in the herbage for the unfertilized, 20, 50, and 80 lb/ac N rates, respectively.

Soil samples obtained on May 18, 1971, from the surface 10 inches on plots seeded to 12-inch row spacings and fertilized with none, 20, 50, and 80 lb/ac N contained a mean N concentration of .063 percent as compared with .058 percent for the controls. Soil N was not influenced by the level of N or the S addition. Mean soil S concentration of nonfertilized plots was .00018 percent. Within fertilizer treatments only N + S caused a significant ($p < .05$) increase, raising the mean soil S concentration to .00084 percent. On May 24, 1972, S in control plots was .0009 percent, but neither N nor N + S caused significant increases.

DISCUSSION

The effect of row width upon herbage production of crested wheatgrass has been shown to equalize in time, if spacing between rows is not excessive (Hull, 1948; Lavin and Springfield, 1955; Reynolds and Springfield, 1953; McGinnies, 1960; and Hyder and Sneva, 1963). These studies show that two to nine years are required to obtain yield equalization. Yields rapidly equalized in this study mainly because of the three favorable moisture years at the beginning of the study period, followed by a strong drought year.

Spacing effects in this study were primarily concerned with spring yield and did not differ greatly from studies that reported hay or full-season yields. This similarity supports an earlier inference by Hyder and Sneva (1961) that yield response after May 15 for this locale is essentially linear. We would conclude from our study that close row spacings (6 and 12 in.), though providing greater spring production during the first two years after seeding, were not superior to wide row spacings over the 10-year production period. The best spacing depends on factors other than production.

Nitrogen fertilizer significantly increased yields on May 15. This response to N is similar to that obtained when harvesting mature grasses (Sneva et al., 1958). The 20 lb/ac N was the most efficient treatment for both spring yield and total harvested yield. Biennial N applications were slightly less efficient than annual applications. Lang and Landers (1968), summarizing 10 years of data in Wyoming, also found that 20 lb/ac N was the most efficient level for increasing yield and concluded that differences between annual and biennial application were small. While interactions between N and RS were significant, these interactions were associated with yields in the first few years when widely spaced grasses were not fully utilizing the site. At the most efficient rate (20 lb/ac N, applied annually), yield on May 15 was increased approximately 64 percent.

Economically, one versus two applications of 20 lb/ac N probably favor the single biennial application. The response to the biennial application will be more variable since a greater proportion of it is utilized in the first year. Further, Sneva (1973) has shown that N can be applied in late winter or early spring without significant loss in efficiency. Delaying fertilization until late winter or early spring provides an opportunity to select those years when moisture supply is adequate to insure near maximum N response. Thus, we concluded that annual applications seem to provide the greatest potential return. We question whether we can use grazing animals on early spring production because of the physiological stress placed upon the grass during the prime root growth and carbohydrate depletion period (Hyder and Sneva, 1961).

Regrowth production of unfertilized plots was 311 lb/ac, which is only slightly above the minimum amount of available herbage required to assure an adequate daily intake of dry matter by grazing steers (Hyder, 1967; Handl and Rittenhouse, 1971) and for cows (Sharp, 1970). The yield increase of 72 lb/ac with 20 lb/ac N is not a practical solution to the problem as these are final yields. Thus, the effect of N on regrowth is minimal and unaffected by RS or frequency of N application.

Nitrogen efficiency for increasing total yield was greater than that for increasing spring yield. Each pound of N applied at the most efficient rate (20 lb/ac) returned about 19.1 lb herbage/lb N/year. This was nearly equal to that reported for full season response by Sneva and others (1958) and Lang and Landers (1968).

Each additional increment of N applied significantly increased the CP in the herbage on May 15; biennial N applications were more effective than annual applications. In the early spring the CP concentrations are important primarily because high N levels have been associated with grass tetany and nitrate poisoning of livestock (Grunes et al., 1970; Anon., 1963). On May 15, CP concentrations in the herbage were indirectly related with mean April temperatures. Thus, a potential exists for using April temperatures to forewarn of N accumulation in plant tissues during May. Grasses at wider row spacings accumulated high CP concentrations only in the beginning years of the study; differences due to row spacings on the 10-year means were nonsignificant. We believe this interaction was caused by the lower yield production by the grasses at wide row spacings in those earlier years. Nitrogen fertilization also caused significant increases of CP concentrations in the regrowth. Since the regrowth would be grazed when the CP of mature grasses is considerably lower, it merits attention for areas like eastern Wyoming where summer precipitation is sufficient to cause more regrowth (Bedell, 1973).

Both RS and N consistently influenced the DM concentrations on May 15. Low DM concentration in early spring herbage may influence animal performance through its restrictive effect on DM intake. Since N-fertilized grasses contained more water than unfertilized grasses, and because more water was contained in grasses spaced widely than in closely spaced grasses, a larger green forage intake would be required for animals grazing fertilized and widely spaced rows than for those grazing unfertilized or closely spaced rows of crested wheatgrass. The effect of row spacing was separate from that of N, as DM concentrations in plants continued to be influenced after the RS effect on plant CP had dissipated. Thus the wide row spacings caused a difference in the soil-plant water economy.

Row spacing effects were small in the second, third, and fourth growing seasons, when increasing N levels caused soil moisture to be used more rapidly at both the 10- and 26-inch depths. However, depletion curves for grasses fertilized at 20 lb/ac N did not differ greatly from those of the controls. Soil moisture in drought years and high N levels in normal years probably caused physiological stress in the grasses before May 15.

Nitrogen significantly increased the concentration of some minerals in grasses during the fifth, sixth, and seventh yield years; year effects also influenced plant mineral concentration. Sulfur was the only mineral whose yield significantly increased by fertilization; thus, the mineral depletion of P, K, or Ca appears to be minimal under N fertilization, but that of S may not be.

Grass yields at 6- and 12-inch row spacings decreased over the 10 years of this study. Decreasing yields with stand age after establishment is quite common in crested wheatgrass (Konstantinou, 1922; Barnes and Nelson, 1950; Bleak and Plummer, 1954; Hyder and Sneva, 1963; Hull and Holmgren, 1964). Lang and Landers (1968) suggested, like others, that the yield decrease most often is associated with the decrease in soil nutrients. Klages and Stark (1949) reported that as grass stands aged the response to N increased. Canode (1958) also reported beneficial response with seed production of crested wheatgrass from a higher N rate as the stand aged. Nitrogen in this study did increase production, yet higher N levels were not more beneficial in the latter years. Further, yields under fertilization decreased like yields of controls. Statistical tests of the regression slopes of fertilized versus unfertilized yields were not significant. Thus N was not the primary factor causing yield decrease of crested wheatgrass as the stand aged.

The Pacific Northwest is considered a sulfur-deficient area (Woodhouse, 1964), with S deficiency reported in many areas (Cheney et al., 1958). However, in the early 1950's no response to S or to N + S on crested wheatgrass or alfalfa growing 0.25 mile from the test plots was observed (Sneva et al., 1964). Because of these results we believe the chlorosis (of varying intensity) associated with N fertilization on these plots was due to other causes, many of which were explored with negative results. In 1970 we analyzed leaf tissue of chlorotic plants and found rather wide N:S ratios. We started a study to explore more fully the response to S.

Nitrogen:sulfur ratios of herbage collected on May 15 in the five years when chlorosis was visually evident were 13.6:1 or less. This is less than the 15:1 generally found throughout the plant kingdom (Thompson et al., 1969) and generally used as the dividing point for indicating S deficiency. In 1971 and 1972 N:S ratios of grasses fertilized with N only rarely exceeded 15:1, yet significant yield response occurred with S additions which decreased the N:S ratio to 11:1 or lower, which was near the N:S ratio found in unfertilized grasses. Either the May 15 sampling did not detect S deficiency at its maximum intensity, or the ratio of 15:1 is not sufficiently narrow to be used for detecting S deficiency in crested wheatgrass.

The additional increase in early spring production with S resulted in N efficiency exceeding 20 lb of herbage/lb of N applied. Twice as much herbage can be produced by May 15 with N + S. Additionally, with S the CP concentration decreased, possibly a growth dilution effect. Thus, adequate S increases the yield and lowers the possibility of nitrate accumulation.

The increase in yield with S is probably accompanied by an added stress on the soil moisture supply and root carbohydrate depletion, which can only further sensitize the plant to any removal practice during this early growth period. We need grazing evaluations to determine if we can apply the "art" in range management to capitalize on these benefits on a sustained basis.

The two years of response data with S suggest that the N response in the previous 10 years may have differed if adequate S had been present in all years. No doubt in some, if not all, of those years, grass response to N was limited by S. The results of the two-year study on S suggest that had adequate S been present during the previous 10 years: (1) mean yields would have been increased, (2) the response curve to increasing levels of N would have remained about the same, and (3) the effects of row spacing would not have been changed. Possibly with S, a slightly higher N rate than 20 lb/ac may be more efficient, but this rate is unlikely to exceed 30 lb/ac.

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