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Fertilization on Sagebrush-Bunchgrass Range

---A Progress Report

D. N. Hyder

F. A. Sneva

Squaw Butte Experiment Station, Burns, Oregon

Jointly operated and financed by the Agricultural Research Service, United States Department of Agriculture and the Agricultural Experiment Station, Oregon State University, Corvallis.

Miscellaneous Paper 115 | **July 1961**

Agricultural Experiment Station • Oregon State University • Corvallis

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FOREWORD

Fertilization studies on sagebrush-bunchgrass range have been underway at Squaw Butte Experiment Station since 1952. This report provides a brief summary of results from completed studies and statements of progress from studies underway. General concepts and trends are emphasized throughout in preference to detailed presentations of data. The fertilization responses reviewed provide a tentative basis for decisions about range fertilization practices and a guide to further experimentation.

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FERTILIZATION ON SAGEBRUSH-BUNCHGRASS RANGE

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I. DESCRIPTION OF THE AREA

A. Location

All of the work reported below was done on Squaw Butte Range. This area is about 42 miles west of Burns on the Oregon High Desert at an elevation of 4,600 feet, and includes 16,000 acres of sagebrush-bunchgrass range. The range is grazed by cattle from late April to October each year.

B. Native Vegetation and Soils

The sites chosen for the various fertilization studies are examples of the *Artemisia tridentata-Agropyron spicatum* habitat type, as classified by R. E. Eckert, Jr., 1957. This habitat type occurs on residual and alluvial soils developed from basalt and rhyolite parent material. The soils developed on alluvial fans are underlain by an indurated restrictive layer cemented either by calcium carbonate or by silica. According to Eckert, these uncorrelated soils are in the Brown great soil group and represent four soil series in the vicinity of Squaw Butte. The soils involved in the fertilization studies are classified as examples of series 7. Surface colors vary from grayish brown to dark grayish brown. The textures vary from a loam in the A horizon to sandy clay loam in the B. A platy structure is found in the A horizon while in the B the primary structural units are moderate prisms, breaking into subangular blocks. The soils are nonsaline throughout and vary in pH from 6.4 to 7.0, except in the calcium carbonate pan where the pH is about 8.0. The A_1 contains about 2.0 to 2.2 percent organic matter, but the surface 6 inches generally contains less than 1.0 percent organic matter. In the surface 6 inches of soil the moisture content at a tension of 1/3 atmosphere is about 17.0 to 20.0 percent and at 15 atmospheres is about 8.0 to 11.0 percent.

C. Climate

Average annual precipitation is 11.8 inches figured on a crop-year basis (July 1 - June 30). In the 20 years 1938-1957 the lowest amount was 6.1 and the highest was 16.8 inches. Average monthly amounts in the 20-year period and actual amounts in the past 8 years are given in Table 1. About 60 percent of the precipitation has fallen in the 6 months of fall and winter. This is a winter precipitation pattern, but it is also important to appreciate that about 25 percent has fallen in May-June.

All months have experienced temperatures below 32° F. The average frost-free period based upon the occurrence of minimum temperatures of 32° or below is 50 days. Temperature records are given in Table 2.

Evaporation from a free-water surface is about 45 inches from April to October 31.

Table 1. Precipitation at Squaw Butte Range (near Burns, Oregon)

		Inches of precipitation by individual crop years:							
Month	20-yr. avg.	'52-53	'53-54	'54-55	'55-56	'56-57	'57-58	'58-59	'59-60
July	0.26	0.00	0.00	0.00	0.57	0.48	0.31	0.36	0.11
Aug.	0.47	0.17	1.03	0.23	0.00	0.38	0.19	0.31	0.51
Sept.	0.59	0.22	0.01	0.09	1.02	0.15	0.43	0.19	0.56
Oct.	1.05	0.00	0.28	0.10	0.49	2.57	3.39	0.00	0.87
Nov.	1.19	1.32	1.30	0.45	1.80	0.18	1.19	0.82	0.00
Dec.	1.41	2.29	1.65	0.70	2.05	0.75	1.80	0.95	0.49
Jan.	1.28	1.20	1.20	0.70	3.20	1.40	2.45	0.90	1.90
Feb.	1.02	1.27	0.35	0.50	1.00	1.19	2.00	0.82	1.65
Mar.	1.01	1.10	0.91	0.70	0.69	3.21	1.00	0.67	1.65
April	0.72	0.57	0.78	1.91	0.20	0.75	0.88	0.25	0.69
May	1.52	3.82	0.93	0.32	3.04	2.70	1.10	1.03	1.64
June	1.30	2.21	1.03	0.41	0.80	0.24	2.01	0.50	0.29
Total	11.8	14.2	9.5	6.1	14.9	14.0	16.8	6.8	10.4

Table 2. Air temperatures at Squaw Butte Range (near Burns, Oregon)

		Individual years							
Month	20-yr. avg.	'52-53	'53-54	'54-55	'55-56	'56-57	'57-58	'58-59	'59-60
A. Average monthly maximum (°F.)									
July	84.6	85.2	86.5	86.4	80.6	85.1	82.0	82.7	88.3
Aug.	83.0	84.4	81.9	78.4	88.8	81.9	78.8	85.3	81.6
Sept.	75.9	79.7	83.2	74.2	76.3	75.9	78.3	71.3	68.0
Oct.	61.8	71.7	67.2	64.4	64.7	64.0	53.6	66.9	61.9
Nov.	46.6	51.3	53.0	55.8	43.8	53.3	44.3	48.3	54.5
Dec.	38.0	38.4	42.6	37.8	40.8	40.7	39.9	43.8	37.8
Jan.	35.4	47.2	39.8	34.7	39.0	30.0	34.3	39.5	32.6
Feb.	39.8	48.5	46.7	40.0	37.0	44.7	43.4	39.5	35.5
Mar.	46.6	49.6	46.8	48.3	49.6	48.7	41.5	49.7	50.7
April	58.3	55.0	60.1	47.1	63.1	57.7	52.0	58.5	54.3
May	65.5	58.0	70.4	61.8	65.3	64.2	71.6	61.1	60.2
June	71.6	66.4	69.0	78.1	69.0	75.2	71.9	77.3	78.2
Mean	58.9	61.3	62.3	58.9	59.8	60.1	57.6	60.3	58.6
B. Average monthly minimum (°F.)									
July	48.8	48.0	48.4	48.9	45.6	51.5	45.5	51.4	50.4
Aug.	47.3	49.8	47.0	44.9	49.4	48.9	46.1	52.5	45.7
Sept.	42.0	43.5	45.4	38.6	40.0	42.5	42.7	38.8	37.6
Oct.	32.7	37.3	33.2	32.0	32.6	31.2	32.4	33.9	34.1
Nov.	23.8	20.3	29.8	28.7	23.1	22.1	21.3	24.2	22.6
Dec.	19.1	19.5	21.0	15.4	21.2	20.6	23.2	24.5	15.6
Jan.	14.9	28.2	19.6	12.0	19.1	7.2	19.9	21.7	17.8
Feb.	19.3	24.0	24.9	16.0	15.6	21.7	27.6	21.8	18.9
Mar.	23.2	24.2	20.9	21.2	23.4	26.4	22.1	23.6	26.4
April	29.1	27.4	29.5	25.2	30.9	29.6	28.4	28.6	28.7
May	35.5	32.3	36.4	32.1	39.7	38.5	41.0	31.3	32.5
June	40.3	37.0	38.1	44.6	40.5	43.1	44.9	42.5	41.3
Mean	31.3	32.6	32.8	30.0	31.8	31.9	32.9	32.9	31.0

II. HERBAGE-YIELD STUDIES OF FERTILIZATION

A. Crested Wheatgrass Response to N

1. Procedure

The initial fertilization experiment was conducted on a 15-year-old broadcast stand of standard crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult). The stand was uniform throughout and included few weeds or other grass species. Ammonium nitrate at 0, 10, 20, 30, and 40 lb N/A was applied broadcast in the fall. Nitrogen rates were assigned randomly to 15 x 15-foot plots arranged in latin square design. New plots were treated in each of the years 1953, 1954, and 1955 when precipitation was above-average, average, and below-average, respectively. Herbage yield samples were obtained by hand clipping one-half of the plot areas on June 1 and the remaining half on August 1. Yield samples were oven-dried, adjusted to 12 percent moisture, and expressed in lb/A. Herbage crude protein contents were determined by the Kjeldahl method. Soil moisture depletion rates were sampled by resistance readings in plaster of Paris blocks placed at 6 and 15 inches below the soil surface.

2. Results

Herbage yields, fertilizer-cost per ton of increased herbage, and crude protein contents are summarized in Table 3. Years, N rates, and the year x nitrogen interaction were sources of significant variation in yields. Fertilization increased

Table 3. Herbage yields and crude protein contents of crested wheatgrass averaged over 3 years

Herbage response	Rate of applied N (lb/A)					LSD 5%
	0	10	20	30	40	
A. Herbage harvested only June 1:						
Yield (lb/A)[a]	270	377	498	578	577	68
Gain/lb of N (lb)	-	10.7	11.4	10.3	7.7	
Cost/ton ($)[b]	-	30	28	31	42	
Crude protein (%)	12.7	12.7	14.0	15.9	16.7	
B. Herbage harvested only August 1:						
Yield (lb/A)[a]	711	774	1017	1031	1176	118
Gain/lb of N (lb)	-	6.3	15.3	10.7	11.6	
Cost/ton ($)[b]	-	51	21	30	28	
Crude protein (%)	4.2	4.8	5.2	6.1	6.7	

[a] Yields expressed at 12% moisture.

[b] N figured at 16¢/lb.

yields each year. The proportionate increases were about the same each year, while the quantitative increases depended upon the amount of precipitation. A ton of herbage cost about $20-40 in this experiment, but the cost was only $13/ton in the wet year, 1953. Yield increases were approximately linear by nitrogen rates of 0, 10, 20, 30, and 40 lb/A. When precipitation was below average, the N response was carried over into the second year after fertilization. Soil moisture was depleted most rapidly on fertilized plots, and this occurrence is interpreted as an intensification of competition for soil moisture.

3. Conclusions

The high cost of herbage by nitrogen fertilization will limit the use of N on the sagebrush-bunchgrass range.

4. Literature citation

Sneva, Forrest A., D. N. Hyder, and C. S. Cooper. 1958. The influence of ammonium nitrate on the growth and yield of crested wheatgrass on the Oregon High Desert. Agronomy Journal 50: 40-44.

B. Spring vs. Seasonlong Response to N

1. Procedure

A 2 x 2 factorial in 5 randomized blocks including 2 levels of N (0 and 30 lb/A) and 2 dates of harvest (May 15 and August 1) was established on a 15-year-old broadcast stand of crested wheatgrass in 1957. Herbage yield samples were hand-clipped, oven dried, and expressed in lb/A at 10 percent moisture. Ammonium nitrate was applied surface broadcast in the fall each year.

2. Results

Yields on May 15 averaged about 0.4 as much as on August 1, but the proportion was lower in wet years (1957 and 1958) and higher in dry years. Yield increases attributed to fertilization averaged about 0.4 as much on May 15 as on August 1. Fertilized plots were 82 and 96 percent more productive than unfertilized plots, respectively, on May 15 and August 1 (Table 4). Nitrogen fertilization apparently stimulated physiological activity prior to May 15 when leaf tissue was being formed, and growth rates after May 15 were directly proportional to the amount of leaf tissue present and active in photosynthesis. Growth began about April 1 on all plots.

The yields of regrowth herbage on plots clipped May 15 averaged 224 and 379 lb/A, respectively, on unfertilized and fertilized plots. Herbage increases per lb. of N were 9.0 on May 15 and 25.0 lb. on August 1. Counting regrowth, the herbage

Table 4. Herbage yields of crested wheatgrass clipped May 15 or August 1 and fertilized with 0 or 30 lb N/A

	Harvested May 15			Harvested Aug. 1		
Year	0#N (lb/A)	30#N (lb/A)	Yield increase (%)	0#N (lb/A)	30#N (lb/A)	Yield increase (%)
1957	167	175	5	1201	2099	75
1958	269	657	144	722	1940	169
1959	347	772	122	574	956	67
1960	454	712	57	674	1179	75
Mean	309	579	87	793	1543	95

increase per lb. of N was 14.2 lb. on plots clipped May 15.

3. Conclusions

The yield response to nitrogen fertilization depended upon the production and accumulation of larger amounts of leaf tissue than occurred without fertilization. Clipping on May 15 limited the yield response to less than half as much as that produced without clipping, and it is assumed that grazing during the season of leaf formation also would limit the yield response. By inference, grazing of fertilized fields should be delayed until about the time of heading to obtain a maximum return from the nitrogen applied.

4. Literature citation

Unpublished.

C. Stand-Density Effects in Crested Wheatgrass Response to N

1. Procedure

An experiment was initiated in 1956 to evaluate nitrogen fertilization on stands varying in density in terms of herbage yields on May 15 rather than at the hay-stage of development in late June. The strip-plot experiment in three replications included drill-row spacings of 6, 12, 24, and 36 inches on whole plots and factorial combinations of nitrogen rates and frequencies of application on strips across whole plots. The treatments in factorial combinations were 5 rates of N (0, 20, 30, 50, and 80 lb/A figured on an annual basis) and 2 frequencies of application (annually and biennially).

Standard crested wheatgrass was seeded in the spring 1956, and ammonium nitrate was applied surface broadcast in the fall each year beginning in 1956. Herbage yields were sampled by hand clipping 48-square-foot center strips at ground level on May 15 each year. The samples were dried in a forced-air electric oven at 70° C., and weights were computed to lb/A at a moisture content of 10 percent. After yield sampling, the plot borders were mowed with a rotary lawn mower.

Gypsum soil-moisture blocks were established at depths of 10 and 26 inches centered between grass rows in each plot of two replications. Resistance readings were obtained at about weekly intervals during the growing seasons beginning in 1957 to evaluate soil-moisture-depletion rates.

Additional procedural details are not pertinent to the results summarized in this report.

2. Results

This report is limited to the yields of crested wheatgrass fertilized annually with 0 and 30 lb/N/A.

Herbage-yield increases attributed to nitrogen fertilization are summarized by individual years in Table 5, part a, and the costs for producing a ton of additional herbage are shown in Table 5, part b.

Row spacing was a source of significant variation among yields, but became less important each year as the grasses in widely spaced rows increased in crown size and lateral root distribution. The level of available soil nitrogen was not limiting to herbage growth in thinly stocked stands. Soil moisture has been depleted more rapidly at all row spacings on fertilized than on unfertilized plots.

The estimated cost of producing an additional ton of herbage by May 15 with nitrogen fertilization was $23, $30, $39, and $33, respectively, with rows spaced 6, 12, 24, and 36 inches apart.

3. Conclusions

Fully stocked stands of crested wheatgrass are needed to obtain a maximum response with nitrogen fertilization. The high cost of additional herbage will restrict the use of nitrogen fertilization for increasing the amount of spring forage on crested wheatgrass seedings.

4. Literature citation

Unpublished.

Table 5. Yield increases on May 15 attributed to fertilization with 30 lb/N/A, and the costs of a ton of additional herbage

Years	Row spacing (inches) 6	12	24	36	Mean
a. Yield increases (lb/A at 10 percent moisture)					
1957	430	105	-43	56	137
1958	323	238	234	104	225
1959	308	449	327	503	397
1960	593	509	458	496	514
Mean	414	325	244	290	318
b. Cost per ton of additional herbage ($)*					
1957	22.30	91.40	-----	-----	70.10
1958	29.70	40.30	41.00	92.30	42.70
1959	31.10	21.40	29.40	19.10	24.20
1960	17.00	18.90	21.00	19.30	18.70
Mean	23.20	29.50	39.40	33.10	30.19

*Costs were computed with nitrogen valued at 16¢/lb.

D. Nitrogen Responses by Twelve Seeded Grasses

1. Procedure

Four selections of crested wheatgrass, 2 each of fairway wheatgrass and hard fescue, and 1 each of siberian wheatgrass, whitmar wheatgrass, tall wheatgrass, and big bluegrass were seeded in May 1952 at 10 lb. of seed per acre in 5-row nursery plots that were 20 feet long and 5 feet wide. The seedings were replicated 3 times and irrigated to insure stand establishment. Two levels of nitrogen (0 and 30 lb/A) were assigned randomly to one-half of each replication in 1956 and applied as ammonium nitrate by surface broadcast in the fall preceding each subsequent year. Herbage yields were obtained from the center 3 rows after seed maturity (approximately August 1). Herbage samples were oven dried and expressed in lb/A at 10 percent moisture.

2. Results

Herbage yields in the first 5 years were reported by Cooper and Hyder. The present report summarizes yields in the past 4 years.

Mean herbage yields, percent increases due to N, herbage gains per pound of N, and the estimated costs of producing an additional ton of herbage by nitrogen fertilization are presented in Table 6. Fertilization was a source of significant variation among yields each year, and the variances due to species and the species by nitrogen interaction were significant in 1957 and 1960.

Table 6. Four-year mean yields of grasses fertilized at 0 and 30 lb N/A with herbage-cost evaluations

Species	Nitrogen treatment		Percent increase1/	Gain/lb of N	Cost/ton2/
	None	30 lb/A			
Poa ampla Merr. (Sherman big bluegrass)	1056	2481	135	48	$ 6.70
Agropyron sibiricum (Willd.) Beauv. (Siberian wheatgrass)	852	2223	160	46	$ 7.00
Agropyron elongatum (Host) Beauv. (Tall wheatgrass)	783	1251	60	16	$20.00
Agropyron inerme (Scribn. & Smith) Rydb. (Whitman wheatgrass)	739	1854	151	37	$ 8.70
Agropyron desertorum (Fisch.) Schult. (Crested wheatgrass)					
Standard	752	1982	164	41	$ 7.80
Mandan 571	873	1806	107	31	$10.30
Nebraska 10	1002	1708	70	24	$13.30
Utah 42-1	874	1792	105	31	$10.30
Agropyron cristatum (L.) Gaertn. (Fairway wheatgrass)					
Fairway	780	1927	147	38	$ 8.40
A.-1770	756	1634	116	29	$11.00
Festuca ovina L.3/ (Sheep fescue)	851	1424	67	19	$16.80
Festuca ovina L. var. duriuscula (L.) Koch (Hard fescue)	688	1234	79	18	$17.60

1/Percent increase = fertilized yield/unfertilized yield - 100.
2/The cost per ton of increased herbage by fertilization is figured at 16¢/lb of N.
3/Data includes only 1958, '59, and '60 yields.

Yield increases attributed to fertilization were directly proportional to the amount of precipitation received. Mean percentage increases were 147, 155, 65, and 74 percent, respectively, in 1957, 1958, 1959, and 1960. *P. ampla*, *A. sibiricum*, and *A. desertorum* were more responsive to fertilization than other species.

3. Conclusions

The responses to nitrogen fertilization by these recently drilled stands were greater than those of old broadcast stands used in previous studies. The costs per ton of increased herbage were estimated at less than $10 for 5 species; namely, *P. ampla*, *A. sibiricum*, *A. desertorum* (standard), *A. cristatum* (Fairway), and *A. inerme*.

4. Literature citation

Cooper, C. S. and D. N. Hyder. 1958. Adaptability and yield of eleven grasses grown on the Oregon High Desert. Journal of Range Management 11: 235-237.

E. Nomad Alfalfa Response to Phosphorus Fertilization

1. Procedure

Nomad alfalfa was planted in rows spaced 1, 2, 3, 4, or 5 feet apart on 30- by 30-foot plots arranced in 3 randomized blocks in the spring 1956. Each plot was subdivided for 0 and 50 lb/A of P_2O_5 in the form of treble superphosphate applied by surface broadcast in the fall 1958. Herbage-yield samples were obtained from 48-square-foot center strips on June 22, 1959, dried, weighed, and expressed in lb/A oven dry. The herbage samples from rows spaced 2 feet apart were retained for crude protein and phosphorus determinations.

2. Results and conclusions

Yield differences among row spacings and between rates of phosphate were not significant. Also, differences in crude protein and phosphorus contents were not significant. Mean values were as follows:

	Rates of P_2O_5	
Evaluation	0	50
Yields (lb/A oven dry)	520	582
Crude protein (Percent)	15.83	16.09
Phosphorus (percent)	0.153	0.155

3. Literature citation

Unpublished.

III. ECOLOGICAL AND PHYSIOLOGICAL EFFECTS OF NITROGEN FERTILIZATION

A. Sagebrush Establishment as Influenced by Continuous Nitrogen Fertilization

1. Procedure

A fertilization experiment with N-rates of 0, 15, 30, 45, and 60 lb/A in three randomized blocks was initiated in 1953 to evaluate long-time effects of fertilization upon the establishment of big sagebrush (*Artemisia tridentata* (Nutt.) Gray). Ammonium nitrate has been applied by surface broadcast each fall. Individual plots are 30- x 60-feet in size. The number of big sagebrush have been counted by height classes on 500-square-foot areas located permanently within each plot.

The experiment was duplicated on three sites, as follows: (a) An area seeded to standard crested wheatgrass in 1951, (b) an untreated native area in poor range condition, and (c) an area in fair range condition that was sprayed with 2,4-D in 1952 to kill the sagebrush. The experiments on sites a and b were initiated in 1953, and the one on site c in 1955.

2. Results

The density of sagebrush over 18 inches tall (termed "old plants") have increased on all sites, but those less than 18 inches tall (termed "young plants") have fluctuated in density. Young-plant numbers have decreased steadily on the crested-wheatgrass site (Figure 1). Some individuals grew into the

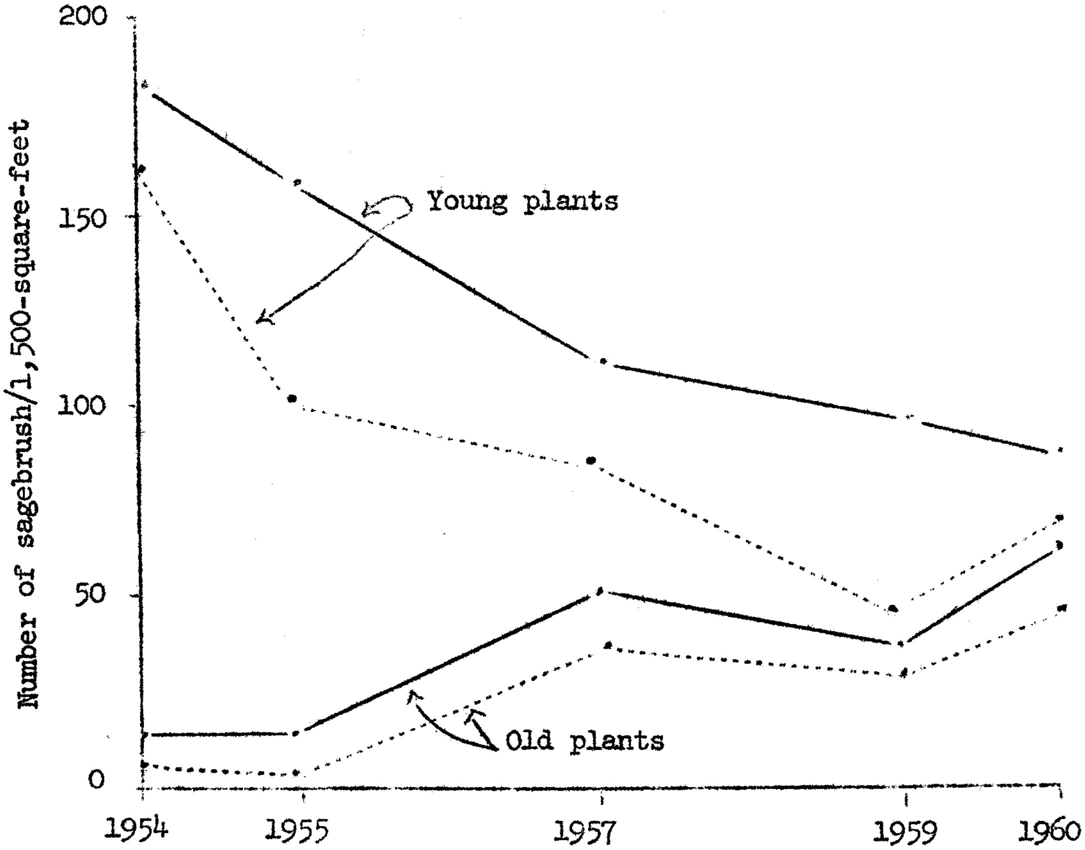

Figure 1. Number of sagebrush on unfertilized (solid lines) and fertilized (broken lines) plots seeded to crested wheatgrass in 1951.

old-plant class--others died. Both mortality and seedling establishment have been greater on fertilized plots. The net effect has been a small sagebrush-control advantage in favor of fertilization. The plots have been grazed heavily by cattle each spring. By inference, it is assumed that fertilization would have affected sagebrush density to a greater extent with less grazing.

Fertilization has "caused" a net increase of sagebrush in each height class on untreated, poor-condition range (Figure 2). The number of seedlings increased greatly in the wet years 1956 and 1957, but most of them had died by 1959. Fertilization improved the conditions for seedling establishment in wet years and resulted in higher mortality rates in dry years. These plots on untreated range have been protected from grazing.

Sagebrush densities on the sprayed-range site have been small. Total densities (all height classes included) are given in Figure 3. Nitrogen fertilization improved the conditions for seedling establishment in wet years and increased mortality rates in dry years. The net effect of fertilization is neither increase not decrease in the rate of sagebrush establishment. New seedlings have appeared in the near vicinity of parent plants. The scattered occurrence of parent plants will limit the rate of sagebrush increase for several years. These plots on sprayed range have been grazed in July or August each summer.

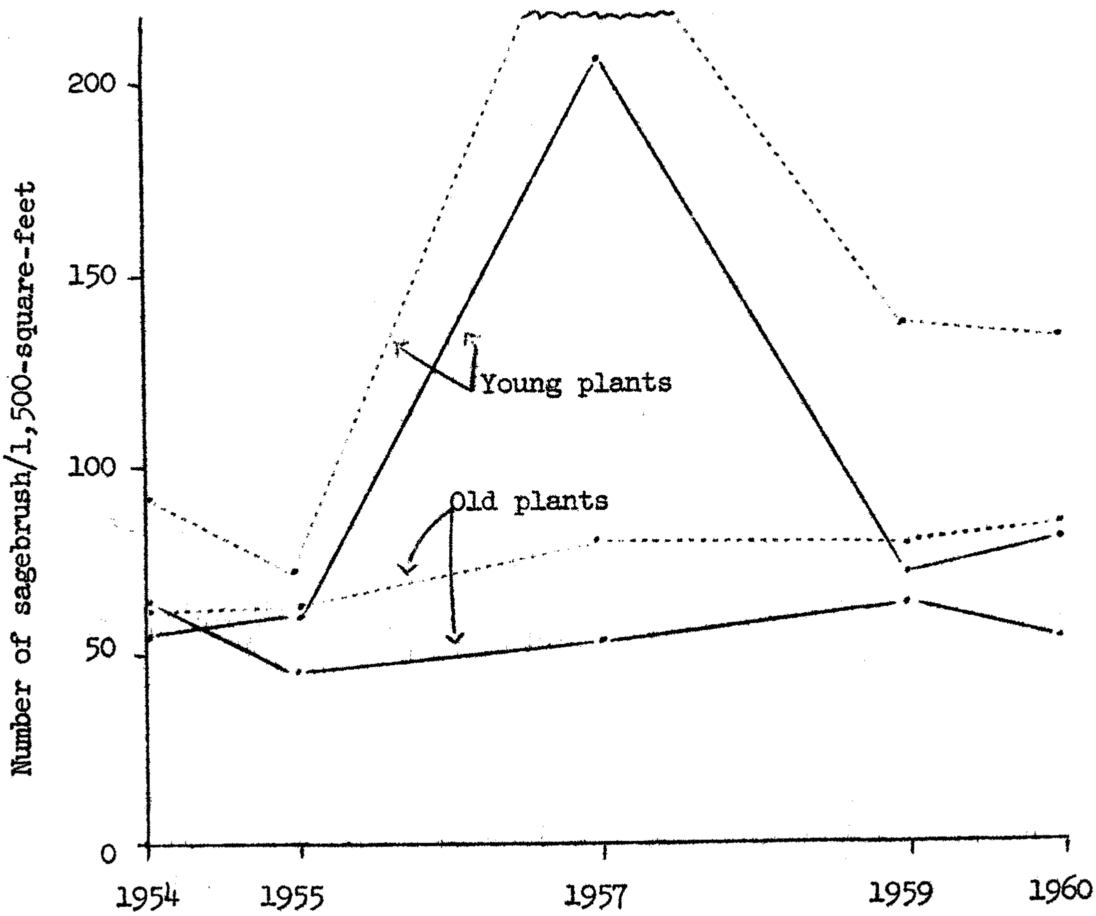

Figure 2. Number of sagebrush on unfertilized (solid lines) and fertilized (broken lines) plots located on poor-condition range.

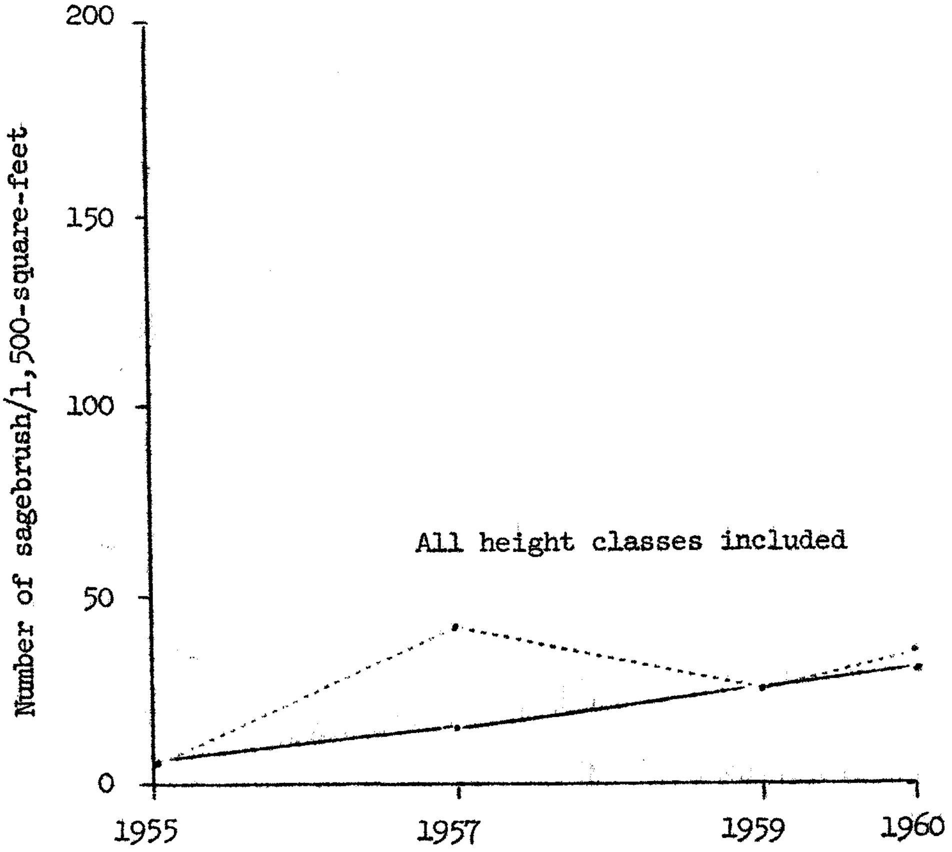

Figure 3. Number of sagebrush on unfertilized (solid line) and fertilized (broken line) plots sprayed with 2,4-D in 1952.

3. Conclusions

Nitrogen fertilization improved the conditions for sagebrush establishment in wet years, but reduced establishment and increased mortality in dry years. The net effects of fertilization have been an increase in sagebrush density on poor-condition range, no cumulative response on sprayed, fair-condition range, and a small decrease in sagebrush density on seeded range. By inference, fertilization net-effects upon sagebrush density are related to the amount of precipitation and to the amount of perennial, herbaceous vegetation. Nitrogen fertilization can contribute a little toward sagebrush control on good-condition range, but will adversely increase sagebrush on poor-condition range.

4. Literature citation

None. The experiments need to continue for 15-20 years to justify final conclusions.

B. Seeding Success and Sagebrush Invasion as Influenced by Nitrogen Fertilization

1. Procedure

A strip 40 feet wide was cleared through a stand of big sagebrush to allow opportunity for brush establishment on seeded plots. The area was plowed, subdivided into plots 40- x 10-feet, and seeded to one of the following species: *Agropyron desertorum*, *A. inerme*, *Poa ampla*, *P. Canbyi*, *A. riparium*, or none. These grasses were drilled in rows going across the full 40-foot width of the cleared strip. *P. canbyi* and *A. riparium* were drilled in rows spaced 6-inches apart, and the other species were drilled in rows 12-inches apart.

The plots were divided along the center line of the cleared strip into two subplots each 10-feet-square, leaving 10-foot borders. One of each subplot-pair was chosen at random for nitrogen fertilization. Ammonium nitrate was applied broadcast at 30 lb N/A in the fall before seeding and was repeated on an annual basis. This was a split-plot experiment in three replications, and the experiment was repeated in three consecutive years. Areas were plowed and fertilized in the fall 1955, 1956, and 1957 and seeded in March 1956, 1957, and 1958, respectively. Seeding success was evaluated by a frequency method using a frame 6-inches square. Stand-percentages were computed from 80 frames per subplot. The number of sagebrush and rabbitbrush seedlings on each subplot were counted in July or August each year.

2. Results

Seeding-success evaluations, averaged for all replications and years, were as follows:

Species	Nitrogen rates 0 lb/A	30 lb/A
A. desertorum	53	57
A. inerme	43	41
P. ampla	33	35
P. canbyi (Canby bluegrass)	64	54
A. riparium (Streambank wheatgrass)	78	77
Mean	54	53

Standard percentages were different among species and equal between fertilization rates. The yields of seedling grasses were taken in 1957 as a measure of fertilization effects during establishment. The yields of seedling grasses and associated weeds are given in Table 7. Nitrogen increased seedling-grass yields and reduced weed yields (largely mustard and cheatgrass). This competitive advantage attributed to fertilization was especially strong with A. desertorum and A. riparium, because they became established most quickly and suppressed weed growth. Total herbage yields were greater on fertilized plots, and indicate greater competition against sagebrush establishment.

The brush (big sagebrush and green rabbitbrush) that became established in the first two years after seeding are summarized over all replications and years, as follows:

Species	Number of brush/900 sq. ft. by fertilization rates:		
	0 lb N/A	30 lb N/A	Mean
A. desertorum	9	9	9
A. inerme	23	17	20
P. ampla	14	11	12
P. canbyi	5	10	8
A. riparium	10	5	8
None (unseeded)	31	17	24
Mean	15	12	14

Fertilization decreased the opportunity for brush establishment on unseeded plots and, to a lesser degree, on seeded plots. The most important differences in brush establishment were among seeded species, and those differences were related to stand-percentages and seedling-yields. Thick stands of the seeded species were effective in limiting brush establishment even with the low-producing P. canbyi. Crested wheatgrass was uniformly vigorous and competitive during establishment.

3. Conclusions

Available-soil-nitrogen does not limit grass survival on these soils, and nitrogen fertilization is an expensive way to gain a little brush control. Seed selection, seeding methods, and chemical herbicides are, in inference, listed as the basis for good seeding success and brush control.

4. Literature citation

Unpublished.

Table 7. Herbage yields (lb/A oven dry) of seedling grasses and associated weeds with and without nitrogen fertilization in 1957

	Unfertilized			30 lb N/A		
Species	Grass	Weeds	Total	Grass	Weeds	Total
A. desertorum	886	54	940	1116	50	1166
A. inerme	350	166	516	356	450	806
P. ampla	158	764	922	306	368	674
P. canbyi	12	586	598	14	612	626
A. riparium	420	444	864	868	6	874
None (unseeded)	0	980	980	0	942	942
Mean	304	499	803	443	405	848

C. Physiological and Morphological Responses of Crested Wheatgrass to Nitrogen Fertilization

1. Procedure

A split-plot experiment in 4 replications was established in 1957. The experiment included 8 clipping dates on whole plots and 2 nitrogen-fertilization rates on subplots. Plots were harvested on one of the following dates: May 7, 21, June 4, 18, July 1, 16, 30, and September 9. The clipping sequence provided an opportunity to investigate growth rates on plots unfertilized or fertilized at 30 lb N/A applied as ammonium nitrate by surface broadcast on March 7, 1957. The plots, measuring 6 x 8 feet, were established on a thick stand of crested wheatgrass that had been drilled in 12-inch rows in the fall 1952. Herbage samples were harvested by hand clipping near ground level and were weighed green, dried in a forced-air electric oven at 90° C., weighed dry, ground in a Wiley mill, and sealed in glass containers for determining the concentrations of crude protein, phosphorus, and potassium.

Samples of underground parts (roots and stem bases) were taken from plots in replications one and three immediately after clipping. The samples were washed, dried, ground, and sealed in glass jars for determining the concentrations of total carbohydrates. Samples of underground parts were taken from plots in replications two and four on September 9 for the determination of autumn-storage-concentrations of carbohydrates. Other procedural details are not pertinent to the points of emphasis made in this report.

The influence of nitrogen fertilization upon stem ratios was evaluated by sampling each plot in an experiment that included five randomized blocks and fertilization with 0 and 30 lb N/A applied as ammonium nitrate by a surface broadcast application in the fall of 1959. Percentages of reproductive and vegetative stems were determined in July 1960.

2. Results

Fertilization with 30 lb N/A increased yields about 94 percent by the time of anthesis. Percentage growth rates by individual growth period show that fertilized grasses grew about twice as fast as unfertilized ones in the two-week period May 7-21. The growth rates were 80 and 38 percent, respectively for fertilized and unfertilized plots (Table 8). After May 21 the percentage growth rates were the same for fertilized and unfertilized plants. Percentage growth rates indicate physiological responses to nitrogen fertilization prior to May 21. However, 65 percent of the yield increase attributed to fertilization accumulated after May 21 when percentage growth rates were equal.

The underground parts of fertilized grasses contained lower carbohydrate concentrations in May and early June and higher concentrations during the remainder of the season. The chronological sequence of differences (fertilized minus unfertilized)

Table 8. Growth rates of crested wheatgrass fertilized with 0 and 30 lb N/A

	Fertilization rate		
Harvest times and growth periods	0	30	difference
May 7 (yields--lb/A)	356	530	174
May 7-21 (yield increases--lb/A)	134	422	288
May 7-21 (yield increases-- %)	38	80	42
May 21 (yields--lb/A)	490	952	462
May 21-June 4 (yield increases--lb/A)	480	878	398
May 21-June 4 (yield increases-- %)	98	92	-6
June 4 (yields--lb/A)	970	1830	860
June 4-July 1 (yield increases--lb/A)	510	955	445
June 4-July 1 (yield increases-- %)	53	52	-1
July 1 (yields--lb/A)	1480	2785	1305

in carbohydrate concentrations was as follows: -4.1, -2.4, -1.8, 0.0, 3.2, 3.2, 2.4, and 0.4 percent. The differences show that carbohydrates were mobilized to a greater extent in fertilized grasses. Maximum mobilization occurred before May 21 while percentage growth rates were higher on fertilized plots. The source of energy that appeared in higher percentage growth rates was provided by the process of carbohydrate mobilization.

The first point of emphasis is that a large part of the yield increase attributed to fertilization depended upon the accumulation of larger amounts of photosynthetic tissue. The second point of emphasis is that larger amounts of photosynthetic tissue were associated with more intensive carbohydrate mobilization.

Differences in autumn-storage-concentrations of carbohydrates (fertilized minus unfertilized) listed according to herbage clipping dates were as follows: 1.2, 3.2, -6.5, 0.9, 3.1, 1.0, 2.1, and 0.4 percent. The greatest difference (-6.5) was found on plots clipped June 4 when herbage removal precluded regrowth and was more detrimental to fertilized grasses. Carbohydrate-storage concentrations favored fertilization on all other plots.

Herbage samples from fertilized plots contained higher concentrations (significant) of moisture, crude protein, phosphorus, and potassium than those from unfertilized plots (Table 9). Fertilized grasses contained more moisture during active growth,

Table 9. Chemical evaluations of crested wheatgrass herbage from fertilized and unfertilized plots in 1957

Fertilization rates (lb N/A	Clipping dates		Moisture (%)	Crude protein (%)	Crude protein (lb/A)	P (%)	P (lb)	K (%)	K (lb)	Ca (%)	Ca (lb)
0	May	7	70	16.1	57	.30	1.07	1.90	6.76	.23	.82
	May	21	68	12.1	59	.26	1.27	1.57	7.69	.20	.98
	June	4	66	9.4	91	.26	2.52	1.73	16.78	.17	1.65
		18	58	6.1	82	.18	2.42	1.12	15.03	.13	1.74
	July	1	50	4.8	71	.15	2.22	1.00	14.80	.13	1.92
		16	43	3.3	52	.11	1.73	.81	12.77	.10	1.58
		30	32	2.6	37	.11	1.57	.73	10.41	.13	1.85
	Sept.	9	21	2.0	27	.07	.96	.63	8.63	.13	1.78
30	May	7	75	23.1	122	.36	1.91	2.37	12.56	.23	1.22
		21	72	17.6	168	.29	2.76	1.90	18.09	.17	1.62
	June	4	68	10.2	187	.23	4.21	2.00	36.60	.17	3.11
		18	60	7.4	220	.17	5.05	1.47	43.69	.13	3.86
	July	1	50	6.0	167	.14	3.90	1.22	33.96	.13	3.62
		16	40	3.7	111	.10	2.99	.93	27.83	.13	3.89
		30	29	3.4	99	.08	2.32	1.02	29.63	.13	3.78
	Sept.	9	20	2.4	56	.07	1.64	.97	22.72	.13	3.04

but lost moisture and cured out more quickly than unfertilized grasses. At the time of anthesis the moisture contents were 50 percent for each treatment.

Crude-protein percentages dropped rapidly during the growing season. Although fertilized grasses contained 7 percent more crude protein than unfertilized ones on May 7, they contained only 0.4 percent more on September 9. Crude-protein yields were maximum at 91 and 220 lb/A on June 18, respectively, for unfertilized and fertilized plots. Only 40 to 45 percent of those amounts remained in the herbage on July 30.

Fertilization increased the phosphorus content of herbage, but the effects were not large. The greatest seasonal differences occurred in May, and the difference decreased gradually during later stages of growth. Peak yields of phosphorus occurred on the same dates as peak yields for crude protein, and the late-season decreases in phosphorus yields suggest translocation to underground parts.

Fertilization increased potassium contents. The concentrations and yields of potassium followed the trends for crude protein and phosphorus. Each of those constituents are relatively mobile in plant tissues, and are subject to translocation in maturing herbage.

Calcium concentrations were not changed by fertilization, but declined gradually to a concentration of 0.13 percent on June 18 and remained at that level as the herbage matured and cured.

Nitrogen fertilization at 30 lb N/A increased the proportion of reproductive stems from 60 to 90 percent in 1960. On other plots the percentage of reproductive stems increased from 24 to 41, 58, and 70 percent, respectively, with row spacings of 6, 12, 24, and 36 inches. Other environmental and physiological factors that affect growth rates in the early spring could have similar effects on stem ratios.

3. Conclusions

A general concept may be stated as follows: Any treatment or condition that promotes the use of a larger quantity of energy in the formation of additional photosynthetic tissue will accelerate the growth rate. This concept applies within the limits imposed by (a) the physiological supply of photosynthate, (b) the morphological adaptations for producing additional leaf tissue, and (c) the environmental factors important to the net assimilation rate.

New growth is at first all leaf tissue, but later the culms arise and eventually new growth is all culm and reproductive parts. Grass growth is plotted as an upward curve in early developmental stages because each growth increment increases the amount of photosynthetic tissue. This corresponds to the principle of compound interest. But compounding ceases and the growth curve becomes linear when new growth increments are due to culm elongation without addition to the effective photosynthetic surface.

Crested wheatgrass has produced a maximum of photosynthetic surface by late May--at the heads-in-boot stage of development. Therefore, the growth rate after than time cannot be accelerated appreciably by cultural treatments. Management and cultural practices devoted to increasing crested wheatgrass yields should promote maximum accumulations of photosynthetic tissue in growth stages prior to the heads-in-boot stage.

Nitrogen fertilization would be of most value if the plants were grazed only after the heads-in-boot stage, because (a) maximum increases in forage would be obtained; (b) root growth and carbohydrate storage would be improved; and (c) the improvement in nutritive quality would be more likely to increase animal daily gains. Nitrogen fertilization should not be proposed for promoting either earlier grazing or heavier stocking rates prior to mid-May.

4. Literature citation

Hyder, Donald N. Growth characteristics of crested wheatgrass, Agropyron desertorum (Fisch.) Schult., in the big sagebrush-bluebunch wheatgrass province of southeastern Oregon. Ph. D. thesis. Corvallis, Oregon State University. 1961.