Effects of Macro- and Micronutrients on the Yield of Crested Wheatgrass[1]

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During recent years interest in fertilization of improved dryland pastures has increased. In the semi-arid West, this interest has been directed toward the fertilization of established crested wheatgrass, (*Agropyron cristatum*) seedings. Work in Oregon (*Sneva, et al.* 1958 and Cooper and Hyder 1958) and in Utah (*Bennet et al.* 1954) has shown that increased production of crested wheatgrass could be obtained by addition of nitrogen.

The objective of this study was to evaluate the use of fertilizers for increasing herbage production on 3 areas seeded to crested wheatgrass. This evaluation was made on sites with infertile soil of granitic origin and where the precipitation was 3 to 4 inches less than on those areas described by the Oregon and Utah workers.

The experiment was divided into two phases: (1) the effect of nitrogen, phosphorus, and sulfur on crested wheatgrass production and (2) the effect of nitrogen alone and in combination with other macro- and micronutrients on crested wheatgrass production.

Description of the Study Area

Phase 1 was initiated in the fall of 1953 at Sweetwater Flat in extreme west-central Nevada at an elevation of approximately 7300 feet. Estimated annual precipitation was 12 inches. The study site was on an alluvial fan with a 5-percent east exposure. Before plowing total ground cover of native vegetation was 20 percent. Big sagebrush (*Artemisia tridentata*) constituted 90 percent of the original cover. The remaining 10 percent was composed of green rabbitbrush (*Chrysothamnus viscidiflorus*), lupine (*Lupinus* sp.), phlox (*Phlox* sp.) spiny skeleton weed (*Lygodesmia spinosa*), squirreltail (*Sitanion hystrix*), needlegrass (*Stipa* sp.), and cheatgrass (*Bromus tectorum*). The soil was approximately 4 feet deep with an increase in clay content in the 41- to 47 inch depth and was classified as a coarse gravelly loam of the Brown Great Soil Group.

Phase 2 was initiated in the fall of 1954 at two locations: Sweetwater Flat (Figure 1) and Paradise Valley (Figure 2). The Sweetwater Flat site was located at the base of the alluvial fan described in phase 1. Native vegetation was similar to that described in phase 1, except that 2 additional species were encountered: muhly grass (*Muhlenbergia* sp.) and dryland sedge (*Carex* sp.). The density of crested wheatgrass in 1955 was 1.5 plants per square foot. Basal area cover of crested wheatgrass was 1.1 percent, as measured on 20 circular 9.6-square-foot plots by the area-list method (Pearse 1935). Maximum and modal sizes of grass plants in 1955 were 80 and 7 square centimeters, respectively.

The soil was approximately 6 feet deep with an A_2 horizon present at 1 to 3 inches and a heavy textured horizon present at the 12- to 17-inch depth. This soil was classified as a coarse gravelly loam of the Brown Great Soil Group.

The Paradise Valley site was located in north-central Nevada at an elevation of approximately 4600 feet. The study area was on the Paradise Grazing Unit (Cloward and Fulwider 1955). Seeding methods have been described by Bleak and Miller (1955). Annual precipitation averaged 8 to 9 inches (Table 1). The study site was on an alluvial fan with a 2-percent east exposure. Ground cover of native vegetation before plowing was 15 percent. Big sagebrush constituted 70 percent of the original cover. Peppergrass (*Lepidium perfoliatum*), yarrow (*Achillea lanulosa*), phlox, bassia (*Bassia hyssopifolia*), squirrel-tail, Indian ricegrass (*Oryzopsis hymenoides*), and cheatgrass formed the herbaceous cover. About 1 plant of crested wheatgrass per square foot formed a basal area of 1.0 percent in 1955. Crown areas of grass plants ranged up to 80 square centimeters. The modal size was 10 square centimeters.

The soil, classified as a loam, varied from 1½ to 2 feet deep, and was placed in the Brown Great Soil Group. A hardpan forms the restrictive layer. Some chemical and physical characteristics of soil from all sites are presented in Table 2.

Methods

Phase 1 of the study was conducted at Sweetwater Flat on a 3-year-old stand of crested wheatgrass which had not been grazed by livestock. The fertilizer treatments were broadcast in the fall of 1953 only and were as follows:

1) 30 pounds of nitrogen per acre as ammonium sulfate (N-30)
2) 90 pounds of nitrogen per acre as ammonium sulfate (N-90)
3) 100 pounds of phosphorus (P_2O_5) per acre as treble superphosphate (P-100)

[1] *Presented at the annual meeting of the American Society of Range Management at Portland, Oregon, February, 1960.*

Table 1. November 1 to June 1 precipitation and deviation from normal.

Year	Sweetwater Flat[1]	Paradise Valley
	——— (Inches) ———	
1954	5.53 — 2.89	....
1955	5.61 — 2.81	3.88 — 2.84
1956	12.68 + 4.26	9.39 — 2.67
1957	5.10 — 3.32	7.97 + 1.25
1958	7.67 — 0.75	9.66 + 2.84

[1] Precipitation values for Sweetwater Flat were taken from Bridgeport, California records.

4) 30 pounds of nitrogen plus 100 pounds of phosphorus (N-30+P-100)
5) 100 pounds of wettable sulfur per acre (S-100)
6) Check N-0).

Treatments were applied at random in each of three replications. Each plot was 8 feet wide and 40 feet long. Mower-strip yields were used for comparison of treatments. An area of 187.5 square feet (5x37.5 feet) was harvested from each plot during July 1 to 20. Herbage yields were expressed as pounds per acre on an oven-dry basis. Treatments were evaluated for 1954 through 1958.

Phase 2 of the study was conducted on two 2-year-old stands of crested wheatgrass. At each location nitrogen, at the rate of 60 pounds per acre, was broadcast over half of the study area. The various macro- and micronutrients were applied at random within the nitrogen treatments in each of three replications. All fertilizer materials were applied in the fall of 1954 only. The treatments were as follows:

1) 200 pounds of P_2O_5 per acre as treble superphosphate
2) 45 pounds of potassium per acre as potassium sulfate
3) 100 pounds of wettable sulfur per acre
4) 20 pounds of copper per acre as copper sulfate
5) 18.5 pounds of iron per acre as ferrous sulfate
6) 10 pounds of magnesium per acre as magnesium sulfate
7) 20 pounds of zinc per acre as zinc sulfate
8) 4.4 pounds of boron per acre as sodium borate
9) 0.3 pounds of molybdenum per acre as ammonium molybdate
10) 36.4 pounds of manganese per acre as maganous sulfate (at Sweetwater Flat only)
11) Check.

Potassium sulfate and sulfur were mixed with 2 quarts of soil and broadcast over the plots. Superphosphate was broadcast and raked into the soil. Micronutrients were applied in water (2 gallons of solution per plot).

Table 2. Some chemical and physical characteristics of the soils of the three study sites.

		Texture					Exchangeable cations (Me./100gm.)		Soluble cations (Me./100gm.)				Cation exchange capacity (Me./100gm.)	Available phosphorus (ppm)	Organic matter (Percent)	Total nitrogen (Percent)
Depth (in.)	Gravel (Percent)	Sand (Percent)	Silt (Percent)	Clay (Percent)	pH	E.C.x10³	Na	K	Na	K	Ca	Mg	(Surface 6 inches of soil)			
PHASE 1—SWEETWATER FLAT:																
0-4	32	74.3	21.7	4.0	6.6	0.43	1.00	0.65	0.02	0.02	0.04	0.02	5.65	22	1.70	0.05
4-9	38	79.6	15.5	4.9	7.2	0.33	0.14	0.44	0.01	0.01	0.06	0.02				
9-15	35	79.6	14.0	6.4	7.0	0.33	0.18	0.37	0.02	0.01	0.04	0.02				
15-23	37	82.9	11.7	5.4	6.7	0.52	0.14	0.33	0.02	0.01	0.06	0.04				
23-41	59	88.2	7.4	4.4	7.1	0.32	0.08	0.22	0.01	0.01	0.03	0.02				
41-47	36	66.7	22.6	10.7	6.9	0.58	0.17	0.25	0.02	0.01	0.05	0.04				
47+	47	77.1	12.2	10.7	6.9	0.40	0.15	0.31	0.02	0.01	0.04	0.03				
PHASE 2—SWEETWATER FLAT:																
0-7	29	74.9	18.1	7.0	7.4	0.68	0.88	0.92	0.02	0.03	0.07	0.03	5.90	25	1.76	0.06
7-12	24	69.5	19.3	11.2	7.1	0.57	0.87	2.04	0.01	0.02	0.10	0.04				
12-17	13	65.6	17.4	17.0	7.2	0.60	0.25	2.36	0.02	0.01	0.01	0.04				
17-31	26	71.3	16.4	12.3	6.9	0.36	0.22	2.62	0.02	0.01	0.04	0.02				
31-50	44	89.1	6.3	4.6	7.1	0.25	0.10	0.10	0.02	0.01	0.02	0.01				
50-56	28	66.5	21.6	11.9	7.0	0.50	0.10	0.14	0.08	0.01	0.04	0.03				
56+	45	82.0	11.0	7.0	7.1	0.30	0.16	0.18	0.02	0.01	0.02	0.01				
PHASE 2—PARADISE VALLEY:																
0-1	6	35.7	54.0	12.3	7.0	0.62	0.24	2.20	0.04	0.02	0.09	0.03	19.54	31	0.96	0.11
1-3	6	38.3	47.2	14.5	7.2	0.46	0.10	2.24	0.02	0.02	0.07	0.03				
3-10	3	47.3	36.4	16.3	7.4	0.64	0.30	1.61	0.06	0.01	0.18	0.06				
10-14	3	51.9	35.2	13.9	7.4	0.98	0.44	0.89	0.08	0.05	0.23	0.06				
14-22	2	57.6	31.4	11.0	7.6	1.35	1.27	0.63	0.04	0.01	0.16	0.06				
22-24	4	62.4	27.6	10.0	7.8	1.86	2.47	0.47	0.62	0.01	0.14	0.06				
24+	4	72.9	17.5	9.6	7.9	2.33	2.66	0.79	0.76	0.01	0.14	0.06				

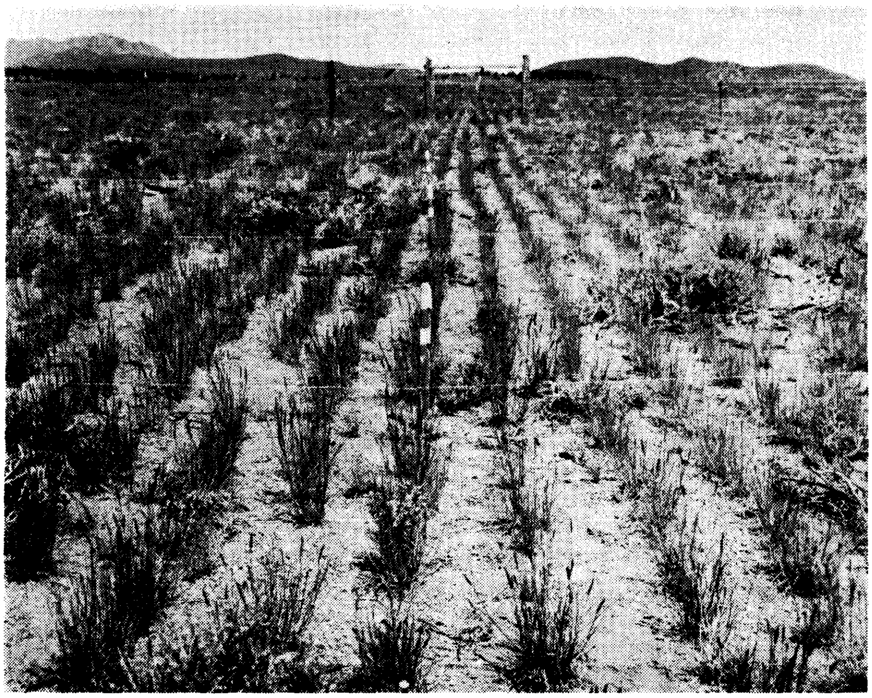

FIGURE 1. Sweetwater Flat, phase 2. Note small size of individual plants. The seeding is 2 years old.

Each treated plot was 7 feet wide and 50 feet long. The yield sample was obtained by hand-harvesting two 50-square-foot plots (5x10 feet). The plot yield was an average of the 2 sub-samples. Sweetwater Flat plots were harvested during July 1 to 20. Paradise Valley plots were harvested during June 16 to July 9. These dates are approximately the time of late grazing at these locations. Yields were expressed as pounds per acre on an oven-dry basis. Treatments were evaluated for 1955 through 1958. In both phases of the study, reinvading brush was removed from the plots by grubbing.

Soil pits were dug at each location and profile descriptions made. A sample from each horizon was collected for laboratory analyses. Stones larger than 2 mm. are reported as percent gravel. The pH of a saturated paste was obtained by a glass electrode meter (method 21b of the U. S. Salinity Laboratory) (1954). Electrical conductivity of a saturation extract was used to appraise the soluble-salt content of the soils (methods 3a and 4b). Soil organic matter was determined by the Walkley-Black method, total nitrogen by the Kjeldahl method, cation-exchange capacity by the flame photometer method, and phosphorus by the sodium bicarbonate method, all as outlined by the Oregon State College Soil Testing Laboratory (1954). Total extractable sodium and potassium were determined by flame photometer analysis of the ammonium acetate leachate from the samples (Bianchi, 1959). Soluble sodium, potassium, calcium and magnesium were determined by flame photometer analysis of saturation extracts from the samples (methods 3a, 10a, and 11a). Exchangeable cations were calculated by difference between total and soluble cations. One-third and 15-atmospheres moisture percentages were determined by the pressure-cooker and pressure-membrane methods, respectively (methods 30 and 31). Mechanical analyses were made by the Bouyoucos method (1951) as modified by Youngberg (1957).

Results and Discussion

Phase 1

Years, treatments, and the year by treatment interaction were significant sources of variation in crested wheatgrass yields.

Herbage yield from all fertilizer treatments showed the same general trend over the 5-year study period (Table 3). Yields were slightly higher in 1955 than in 1954. In 1956, the wettest year

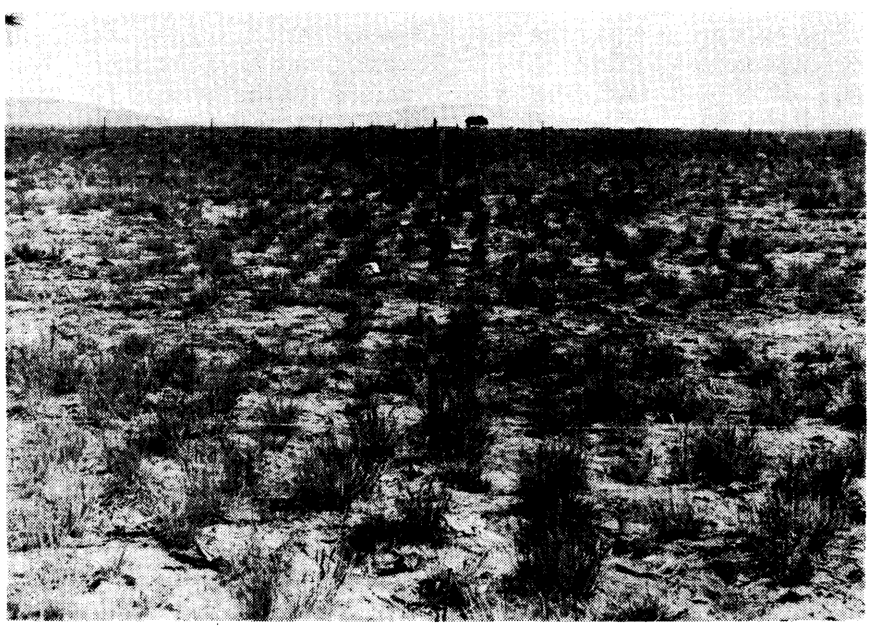

FIGURE 2. Paradise Valley, phase 2. Note large size of individual plants. The seeding is 2 years old.

Table 3. Response of crested wheatgrass to fertilizer treatments in phase 1 of the study expressed in terms of herbage yield, nitrogen efficiency and percent of unfertilized yield. Treatments were applied only in the fall of 1953.

	Herbage yield[1]					
Treatment	1954	1955	1956	1957	1958	5-year mean
	(Pounds per acre, oven dry)					
Check (N-0)	80[a2]	122[a]	249[a]	200[a]	282[a]	187
N-30	175[b]	204[b]	449[b]	224[a]	360[a]	282
N-90	217[b]	268[b]	541[b]	349[b]	374[a]	350
N-30 + P-100	180[b]	193[b]	413[b]	242[a]	329[a]	271
P-100	85[a]	122[a]	297[a]	201[a]	317[a]	204
S-100	108[a]	150[a]	319[a]	208[a]	265[a]	210
Yearly mean	141	173	345	237	321	

[1] Each figure is a mean of 3 replications.
[2] Within-year means followed by the same letter do not differ significantly (5%) (Duncan, 1955).

of the study period, production from all treatments including the check was approximately double that obtained in 1955. Percentage increase were approximately the same for all treatments. In 1957, the driest year of the study period, the check yields showed a 20-percent decrease while reductions in other treatments varied from 35 to 50 percent as compared to 1956 yield. In 1958, an average moisture year, yield increases varied from 107 to 161 percent of 1957 production.

A single application of N-90 resulted in a highly significant increase in yield in each of the first 4 years of the study when the check, P-100, and S-100 treatments are used as the basis for comparison (Table 3). In 1954, 1955, and 1956, the N-90 treatment was not superior to either the N-30 or the N-30+P-100 treatments. In 1957, N-90 was superior to all other treatments. A single application of N-30 or N-30+P-100 resulted in significant yield increases in each of the first 3 years of the study when the check, P-100, and S-100 treatments are used as the basis for comparison. Differences in yield between the N-30 and N-30+P-100 treatments were not significant in any year. The P-100 or S-100 treatment failed to give a yield response in any year.

The average 1954 check yield of only 80 pounds per acre and the general increase in check yields and number of flower stalks due to protection for a 5-year period suggest that the grass stand may not have been mature (in the sense of full utilization of the limiting factors of the habitat) at the start of the experiment. Application of nitrogen, together with protection for a 1- to 2-year period, brought about the same end results as did protection alone for a 3- to 4-year period: increased yield and an increase in the number of flower stalks. Hence fertilization, in addition to increasing yield, may also hasten the maturity of slowly developing stands. Rogler and Lorenz (1956) noted that nitrogen application speeded the recovery of overgrazed fields.

Nitrogen efficiency (pounds of additional herbage per pound of nitrogen applied) varied with years and rate of nitrogen application (Table 4). The greatest efficiency was in the wettest year and with the N-30 rate. On this kind of site, 90 pounds of nitrogen per acre was not used as efficiently over a 4-year period of variable precipitation, as was 30 pounds of nitrogen. For the years of significant response, the total efficiency was 12.6 and 8.0 pounds, respectively, for the N-30 and N-90 rates. The greatest percent increase in yield due to nitrogen occurred in 1954, the first year after fertilization.

The 4-year yield response on plots fertilized with N-90 and

Table 4. Nitrogen efficiency (pounds of additional crested wheatgrass herbage per pound of nitrogen applied) and percent of unfertilized yields.[1]

	1954		1955		1956		1957			
Treatment	Efficiency	% of unfertilized yield	Efficiency	% of unfertilized yield	Efficiency	% of unfertilized yield	Efficiency	% of unfertilized yield	Total efficiency from a single application of fertilizer	Average % of unfertilized
N-O		100		100		100		100		
N-30	3.2	219	2.7	167	6.7	180			12.6	184
N-90	1.5	271	1.6	220	3.2	217	1.6	174	8.0	211

[1] For years of significant response only.

[2] *Richard E. Eckert, Jr., Raymond A. Evans, and Floyd E. Kinsinger. Determination of critical levels of nutrients for range forage plants and range weeds of the intermountain area.*

Table 5. Average yield of crested wheatgrass in phase 2 of the study expressed as herbage yield, nitrogen efficiency, and percent of unfertilized yields.

Location and Year	Treatment N-0	Treatment N-60	Year mean	Nitrogen efficiency	Percent of unfertilized
	(Pounds per acre, oven-dry)				
Sweetwater Flat:					
1955	374[a] [1/2]	424[b]	399	0.8	113
1956	564[a]	766[b]	665	3.3	136
1957	499[a]	533[a]	516		
1958	522[a]	476[a]	499		
Paradise Valley:					
1955	303[a]	337[b]	320	0.6	111
1956	886[a]	1209[b]	1048	5.4	136
1957	827[a]	1155[a]	991		
1958	474[a]	670[a]	572		

[1] Each yield figure is a mean of 30 values from macro- and micronutrient treatments.
[2] Within-year means followed by the same letter do not differ significantly (5%).

the 3-year response from N-30 indicate that (1) nitrogen was not fully utilized each year and that the unutilized nitrogen remained in the soil and was available to plants the succeeding years or (2) the development of the grass root systems increased the first year after fertilization. Crested wheatgrass plants on unfertilized plots could be pulled easily from the gravelly loam soil. Plants on the fertilized plots were harder to pull because they had a much better developed root system. Unpublished data[2]—have shown that roots of crested wheatgrass plants grown under poor nitrogen-nutrition conditions are mostly unbranched, whereas roots of plants grown under adequate nitrogen-nutrition conditions develop a well-branched system. Yield responses at Sweetwater Flat in succeeding years after fertilization may be a reflection of the increase in vigor of the root system.

Problems dealing with a measured residual response from nitrogen fertilization have not been solved. Sneva *et al.* (1958) suggest that since soil-nitrate content at the 0-to 6-inch depth differed only slightly between years, at least part of the residual nitrogen was in the form of root reserves of crested wheatgrass. Kay *et al.* (1957) found that cheatgrass yields were increased significantly for 3 years after an initial application of 120 pounds of nitrogen per acre. Since cheatgrass is an annual, nitrogen would not be stored as root reserves. However, nitrogen could be released through decomposition of the roots or this element could remain in the soil as unutilized nitrates or exchangeable ammonium ions. White *et al.* (1958) reported that residual nitrogen in the soil the year after fertilization of corn resulted in a significant increase in oat yields. These authors also showed that residual soil nitrogen was in the form of nitrates and that most of the nitrates were found in the 12- to 21-inch depth of soil. The applied nitrogen also had no significant effect on the level of exchangeable ammonium or nitrification rate of the soil sampled the following spring.

Typically, ranges seeded to grass have residual or reinvading species of inferior character. Sagebrush, rabbitbrush, and halogeton, for example, continue to grow after crested wheatgrass is dormant. Therefore any residual nitrogen in the soil is available to these weedy species. The growth and seed production of the undesirable plants may be increased. Increased competition with the seeded species would result.

On the basis of 15 cents per pound of nitrogen, a 3-year increase from 30 pounds of nitrogen cost approximately 28 dollars per ton of crested wheatgrass. The 4-year response from 90 pounds of nitrogen costs approximately 37 dollars per ton of grass. Obviously the cost of alternative methods of obtaining forage, e. g. hay, pasture, or unimproved range of equal nu-

Table 6. Yield of oven-dry crested wheatgrass herbage per acre at the Paradise Valley site as influenced by macro- and micronutrients applied without nitrogen (N-0) and with nitrogen (N-60)[1]

Treatment	Macro- and micronutrients + N-O	Macro- and micronutrients + N-60
	(pounds)	(pounds)
Check	352[a] [2]	346[a]
Copper	328[ab]	383[a]
Boron	314	380[a]
Magnesium	304	276[a]
Iron	302	349[a]
Sulfur	299	322[a]
Zinc	295	330[a]
Phosphorus	295	311[a]
Potassium	276[bc]	295[a]
Molydenum	265[c]	376[a]

[1] Each figure is a mean of 3 replications.
[2] Means followed by the same letter do not differ significantly (5%). Means without superscripts are not significantly different from each other or from the high or low groups.

tritive value makes range fertilization impractical on sites similar to Sweetwater Flat.

Phase 2

Years, nitrogen, and the nitrogen-by-years interaction were significant sources of variation in crested wheatgrass yields at both Sweetwater Flat and Paradise Valley. In addition, micronutrients and the nitrogen-by-micronutrients interaction were significant sources of variation in crested wheatgrass yields at Paradise Valley in 1955. Yearly response to nitrogen, percent of unfertilized yield and efficiency at both locations are presented in Table 5.

As in phase 1, maximum yields at both locations were obtained in 1956 (Table 5). At Sweetwater Flat this was the wettest year of the study period, while at Paradise Valley, 1956 was a year of above-average precipitation. Percent of unfertilized yields and nitrogen efficiency were also greatest in 1956 at both locations.

Application of 60 pounds of nitrogen per acre resulted in a significant increase in yield at both locations the first 2 years after fertilizer application. A significant increase in yield the second year after fertilization indicates, as discussed previously, that in some manner crested wheatgrass plants benefited from nitrogen applied at the beginning of the study.

At Paradise Valley in 1955, molybdenum and potassium without nitrogen resulted in yields significantly less than the check (no nitrogen and no macro- or micronutrients) Table 6). In addition, response to molybdenum without nitrogen was significantly less than to copper without nitrogen. With nitrogen added, yield differences among macro- and micronutrients were not significant. In all cases but 2, addition of nitrogen to the various macro- and micronutrients did not result in a significant yield increase. Addition of nitrogen to the molybdenum and boron treatments resulted in yields significantly greater than from the molybdenum and boron treatments without nitrogen. The data suggest a depressing effect from molybdenum and potassium. The depressing effect of molybdenum in particular seems to be corrected by nitrogen. The results also suggest that significant increases in yield may be expected by nitrogen fertilization of range soils high in molybdenum and boron.

There was no macronutrient or micronutrient response except to nitrogen during the remaining years of the study at Paradise Valley and no response except to nitrogen in any year at Sweetwater flat.

Based on the cost of nitrogen at 15 cents per pound, the 2-year significant increase in yield at Sweetwater Flat and Paradise Valley from a single application of 60 pounds of nitrogen cost approximately 71 and 50 dollars, respectively, per ton of grass. Because of the high investment in nitrogen and the lack of an economical response from macronutrients and micronutrients, fertilization of established crested wheatgrass plants on these range sites with the materials and rates used would be impractical.

Summary

The study reported was divided into 2 phases: (1) effect of nitrogen, phosphorus, and sulfur on crested wheatgrass production at 1 location, and (2) effect of macro-and micronutrients on crested wheatgrass production at 2 locations.

N-90, N-30, P-100, N-30+P-100, S-100, and a check were the treatments in phase I. Fertilizers were applied in the fall of 1953 only. Treatments were evaluated for 1954 through 1958. N-60, P-200, K-45, S-100, Cu, Fe, Mg, Zn, B, Mn, Mo, and a check were applied in phase 2. Fertilizers were applied in the fall of 1954 only. Treatments were evaluated for 1955 through 1958.

In phase 1, the N-90 treatment gave a significant yield response in each of the first 4 years after application. The N-30 and N-30+P-100 treatments gave significant yield responses in each of the first 3 years after application. The P-100 and S-100 treatments did not give significant response in any year. The form and location of residual nitrogen in the soil, if any, and any indirect effect of nitrogen on plants were not evaluated.

In phase 2, application of N-60 resulted in a significant increase in yield at 2 locations the first 2 years after fertilizer application. At 1 location, no response from phosphorus, potassium, sulfur, or micronutrients was measured. At the other location, molybdenum and potassium without nitrogen resulted in yields lower than the check. With nitrogen, macro-and micronutrients gave similar yields. Molybdenum and boron with nitrogen gave higher yields than did molybdenum and boron without nitrogen.

Fertilization of the sites described with the rates and materials used would not be practical.

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