Ecological Effects and Fate of N Following Massive N Fertilization of Mixed-Grass Plains

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Highlight: *The response of range herbage and soils on mixed-grass range in southeastern Wyoming to single massive applications of N fertilizer was studied from 1969 to 1973. Herbage yields and N content of herbage were increased by fertilizer in all years of study. Peak responses occurred in 1970 and 1971. Most of the applied N was accounted for in 1970 in top growth and in mineral form. However, a substantial portion could not be accounted for in 1972-73. In early April, 1973, a significant part of the applied N was concentrated below the zone of main root activity in the soil and may be unavailable for future plant use. Several undesirable plants were increased by massive applications of N, and some desirable plants decreased. Massive applications of N on this rangeland produced both desirable and undesirable responses.*

Forage production on rangelands is limited by both available soil moisture and soil nitrogen (N). Only the soil-N supply can be readily increased. Rarely have N fertilizers been applied on rangelands at rates exceeding 112 kg/ha. However, recent investigations have shown substantial and long-term increases in forage production and nutrient quality from single massive applications of N at rates as high as 1,095 kg/ha (Choriki et al., 1968; Johnston et al., 1967).

Massive applications of N on rangelands at long intervals may cost less than annual, smaller applications. Fertilizer N applied in excess of the N-immobilizing capacity of the soil may remain in the soil as mineral N until used (Power, 1972). It appears that saturation of the soil profile with N fertilizer may provide residual soil N for a period of years, or require only small additional amounts of fertilizer periodically to replace that used by plants (Power and Alessi, 1971). This would result in maximum productivity from the available precipitation.

High rates of N fertilizer cause rapid and long-term changes in botanical composition. On the shortgrass plains of north-central Colorado, N fertilization substantially increased the annual forbs, slimleaf goosefoot (*Chenopodium leptophyllum* Nutt. ex Moq.), prairie sunflower (*Helianthus petiolaris* Nutt.), and Russian thistle (*Salsola kali tenuifolia* Tausch); and reduced the pioneer perennial grasses, sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray) and red threeawn (*Aristida longiseta* Steud.) on both abandoned cropland (Hyder and Bement, 1972) and native range (Houston and van der Sluijs, 1973b). On mixed-grass range, substantial increases in annual species and perennial wheatgrasses were shown by Choriki et al. (1968) and Johnston et al. (1967).

The study of range herbage, soil-N, and compositional responses of mixed-grass range to massive rates of N fertilization was conducted from 1969 to 1973. This paper reports the responses of herbage yields, plant N, soil mineral N, and botanical composition. The nitrate-N responses of major and potentially toxic species were previously reported (Houston et al., 1973).

Methods and Materials

Experimental plots 4.6 × 15.2 m were established on mixed-grass range about 8 km south of Cheyenne, Wyoming. The plots were replicated in three randomized blocks. Single applications of ammonium nitrate, at three rates of N (224, 448, and 672 kg/ha), were made in April, 1969.

The dominant species were blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) and western wheatgrass (*Agropyron smithii* Rydb.). The soil was noncalcareous and alkaline (pH 8.0) in the surface 15 cm. It was classified as a Sligo clay loam, with intermittent gravel below 80 cm.

Herbage was harvested at ground level in mid-July of 1969 through 1972. Herbage samples were oven-dried at 70°C, weighed, and ground through a 1-mm screen. Total plant N was determined by the micro-Kjeldahl technique.

Duplicate soil cores were obtained to 100-cm depths in September, 1970, and in April, 1973, on each plot. The cores were separated into 10-cm segments, immediately oven-dried at 70°C, and crushed. Soil samples were analyzed for nitrate-N by the 2,6-xylenol method, slightly modified (Sabatka et al., 1972). Ammonium-N concentrations were determined by soil extraction with acidified NaCl as described by Jackson (1958).

Botanical composition was determined from frequency of occurrence in 100 quadrats on each plot each year. A 40- ×

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41-cm quadrat frame was used for all species (Hyder et al., 1965).

Precipitation was below average during the cropyear (preceeding September through following August) of 1969, particularly during the critical fall and spring months (Fig. 1). Precipitation was above average in the fall and spring months of the 1970 and 1971 cropyears, but late spring and summer precipitation was below average. Precipitation was about average for 1972, except that the winter months were dry. Total cropyear precipitation was below the long-term average of 36.9 cm in all years of study.

Results

Herbage Yields

Average herbage yields for the 4 years 1969-72 were increased by ammonium nitrate treatments (Table 1). The 448-kg N rate increased yield only slightly the first growing season after application, but increased yield substantially in remaining years. Greatest increase in yield over all years was on the 672-kg N treatment. However, the 224-kg rate produced nearly the same total yield as the 672-kg N in 1969, the first growing season after treatment. Average yields were highest in 1971, the third growing season, and lowest in 1970. Percentage increases in yield from the N treatments were greatest in 1970, ranging from 72% for the 224-kg N treatment to 125% for the 672-kg N.

N Concentration and N Yield of Herbage

Ammonium-nitrate fertilizer increased total N concentration of herbage each year of study (Table 2). The 672-kg N rate produced higher concentrations of plant N than other treatments in all years except the first. Over the 4 years of study, single applications of 224 and 448 kg N/ha more than doubled total yield of N (herbage yield multiplied by percent N). The 672-kg N more than tripled average yield of N. Peak yields of N were found in 1971, the third growing season.

N Concentration in Soil

By September, 1970, the nitrate-N and ammonium-N in the soil were concentrated at different depths. Nitrate-N had

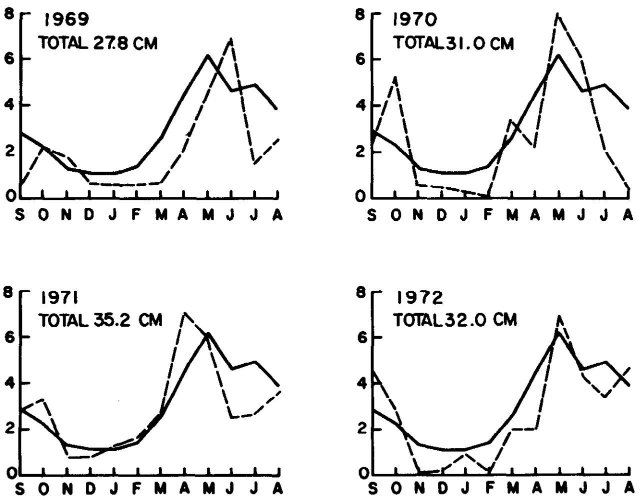

Fig. 1. *Monthly precipitation during the cropyears (preceeding September through current August) of 1969, 1970, 1971, and 1972 (dotted lines), 101-year average (solid lines), and cropyear totals at Cheyenne, Wyoming.*

Table 1. Herbage yields (kg/ha, oven-dry) harvested for 4 years following fertilization with ammonium nitrate in April, 1969.

Year of harvest	Rate of N applied (kg/ha) 0	224	448	672	Avg
			Yield		
1969	1,080b[1]	1,490a	1,190ab	1,510a	1,320b
1970	610c	1,060b	1,120ab	1,380a	1,050c
1971	1,040c	1,610b	1,910a	2,040a	1,630a
1972	840c	1,270b	1,390b	1,690a	1,300b
Avg	890b	1,360a	1,400a	1,660a	

[1] Treatment means within each year or column or row of averages that are followed by the same letter are not significantly different at the 5% level.

moved down from the surface and was concentrated between the 20- and 90-cm depths, with a distinct accumulation between 50 and 70 cm (Fig. 2). The less mobile ammonium-N was concentrated in the top 20 cm of soil. Concentrations of both nitrate-N and ammonium-N were in direct proportion to the rates of N fertilizer applied.

Between September, 1970, and April, 1973, nitrate-N moved still lower in the soil profile, with a substantial accumulation between the 60- and 90-cm soil depths. Nitrate-N concentration at these depths was substantially greater in 1973 than in 1970 for the two highest rates of N applications. In 1973, 224-kg N produced only a slight accumulation below 80-cm. The accumulation of nitrate-N found on this treatment was substantially lower in 1973 than in 1970. In 1973, the accumulation of ammonium-N in the soil profile was about the same for all N rates, with a slight accumulation between 10- and 30-cm.

Fate of Fertilizer N

The amounts of N found in the herbage and the soil were summed to account for fertilizer N. In the fall of 1970, nearly all applied N was accounted for, except where 448 kg N was applied (Table 3). One hundred-six percent, 58%, and 89% of the N applied at the 224-, 448-, and 672-kg N rates, respectively, were accounted for. Soil sampling may have been inadequate to account for the N remaining from the 448-kg rate.

In early April, 1973, only 57%, 55%, and 77% of the N applied at 224-, 448-, and 672-kg N rates were accounted for. Four-year accumulation of N in the herbage was approximately double that found after 2 years. However, amounts of mineral N found in the soil in early 1973 were much less than in 1970. One hundred to 200 kg N/ha could not be accounted for.

Frequency of Species Occurrence

Thirty-six species were present on the experimental site in sufficient abundance for recording. Frequency of occurrence of 18 species was not affected by massive rates of N fertilization, but was significantly different between years of sampling (Table 4). Frequency of five species was not influenced by either massive rates of applied N or year of sampling. Frequency of 13 other species was significantly influenced by massive N treatments. These species are discussed individually.

Blue grama was the most common species on the site. Mean frequency percentage was 100% for all N treatments from 1969 through 1971. In 1972, frequency was reduced from 100% to 40% by the 672-kg N, reduced to 80% by both 224

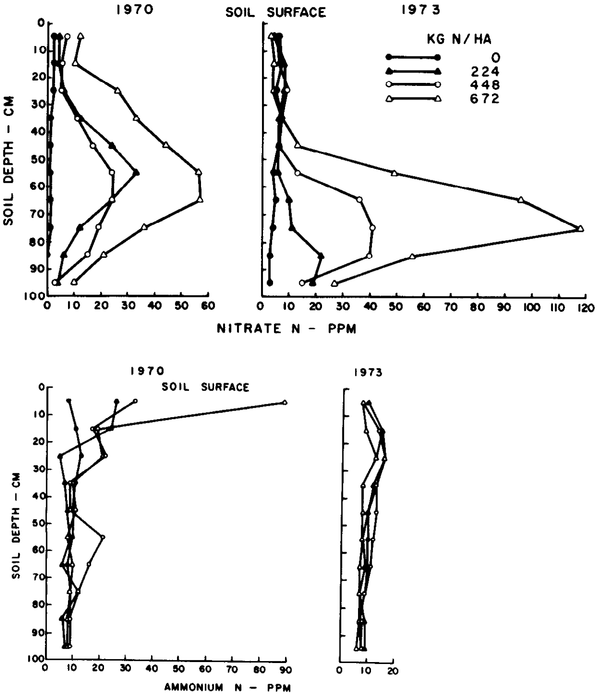

Fig. 2. *Nitrate-N and ammonium-N concentrations in the soil profile in September, 1970, and April, 1973, after single applications of ammonium nitrate fertilizer in April, 1969.*

and 448 kg N, and was unchanged at 100% on the untreated control.

Western wheatgrass was the second most abundant and highest yielding species. Mean frequency percentages by year of sampling and N rates were as follows:

Year	0	224	448	672
1969	49	75	85	73
1970	83	88	92	88
1971	74	77	84	77
1972	79	91	86	92

In this study, western wheatgrass responded more in herbage production than in frequency of occurrence. All N treatments increased frequency of western wheatgrass above that of the control treatment at the first sampling in 1969. In 1970 and 1971, frequency of western wheatgrass was not different among treatments. In 1972, only 224 and 672 kg N increased frequency above that on the control treatment.

Moderate drought in 1969 and in 4 previous years had reduced the stands of western wheatgrass. Thus, near-normal precipitation in 1970 and 1971 increased stands even on unfertilized plots.

Frequency of needleandthread (*Stipa comata* Trin. & Rupr.) was slowly reduced during the study by all rates of applied N. Mean frequency percentages by year of sampling and N rates were as follows:

Table 2. Percentage N (%) in herbage and yield (kg N/ha) of total N harvested for 4 years following fertilization with ammonium nitrate in April, 1969.

Year of harvest	Rate of N applied (kg/ha)				
	0	224	448	672	Avg
Percent N					
1969	1.2c[1]	2.1b	2.3a	2.1b	1.9b
1970	1.5c	2.4b	2.4b	2.6a	2.3a
1971	1.2c	1.7b	1.7b	2.1a	1.7c
1972	1.4c	1.5bc	1.6b	1.8a	1.6d
Avg	1.3c	1.9b	2.0b	2.2a	
Yield of N					
1969	13.0	31.4	27.3	31.7	
1970	9.2	25.3	26.8	35.8	
1971	12.5	27.4	32.6	42.9	
1972	11.5	19.3	21.6	30.2	
Sum	46.2	103.4	108.3	140.6	
Difference	–	57.2	62.1	94.4	

[1] Treatment means within each year or column or row of averages that are followed by the same letter are not significantly different at the 5% level.

Table 3. Location and amounts (kg/ha) of fertilizer N accounted for in 1970 and 1973 following fertilization with ammonium nitrate in April, 1969.

Year and rate of N fertilizer	N in soil 1 m deep ($NO_3 + NH_4$)	N in herbage	Total	Amount of fertilizer N accounted for
1970				
0	152	22[1]	174	–
224	355	57	412	238 (100%+)
448	382	54	436	262 (58%)
672	702	67	769	595 (89%)
1973				
0	217[2]	46[3]	262	–
224	287	103	390	127 (57%)
448	402	108	510	247 (55%)
672	638	141	779	516 (77%)

[1] Total yield of N in herbage for 1969 and 1970.
[2] Soil N determined in early April, 1973.
[3] Total yield of N in herbage for 1969-72.

Table 4. Mean frequency of plant species that were not affected by N fertilization.

Species[1]	Mean frequency percentage
Sum sedge (*Carex heliophylla* Mackenz.)	82
Sixweeks fescue (*Vulpia octoflora* (Walt.) Rydb.)	62
Scarlet globemallow (*Sphaeralcea coccinea* (Pursh) Rydb.)	58
Thickspike wheatgrass (*Agropyron dasystachym* (Hook.) Scribn.)	24
Woody buckwheat (*Eriogonum effusum* Nutt.)	23
Erect knotweed (*Polygonum erectum* L.)	21
Bluebell (*Mertensia lanceolata* (Pursh) A. DC.)	20
Redowski sticktight (*Lappula redowski* Hornem.) Greene	17
White biscuitroot (*Cymopterus acaulis* (Pursh) Raf.)	14
Textile onion (*Allium textile* Nels & Macbr.)	11
Whitlowwort (*Draba nemorosa* L.)	11
Common starlily (*Leucocriunum montanum* Nutt.)	5
Tansymustard (*Descurainia pinnata* (Walt.) Britt.)	5
Scarlet gaura (*Gaura coccinea* Nutt. ex Pursh)	4
Smallflower cryptantha (*Cryptantha minima* Rydb.)	3
Wooly plantain (*Plantago purshii* Roem. & Schult.)	3
Bladderpod (*Lesquerella macrocarpa* A. Nels.)	1
White penstemon (*Penstemon albidus* Nutt.)	1
Hairy goldaster (*Heterotheca villosa* (Pursh) Skinners)	4
Ironplant goldenweed (*Haplopappus spinulosus* (Pursh) DC.)	4
Threadleaf sedge (*Carex filifolia* Nutt.)	2
Eveningprimrose (*Oenothera coronopifolia* Torr. & Gray)	2
Yellow biscuitroot (*Musineon divaricatum* (Pursh) Nutt.)	1

[1] The first 18 species were not affected by the N fertilization but did change between years. The last five species were not affected by either fertilizer or years.

Year	0	224	448	672
1969	61	74	82	71
1970	53	34	47	55
1971	65	27	42	42
1972	54	18	24	15

In 1969 and 1970, frequency of needleandthread was not different among treatments. In 1971 and 1972, all N treatments reduced frequency. In 1972, N treatments reduced frequency of needleandthread an average of 34 percentage points below that of the control. This represented an average decrease in apparent plant density of about 73% where density = - $\log_e$ (q/100) and q = 100 - frequency percentage (Greig-Smith, 1957).

Frequency of Sandberg bluegrass (*Poa secunda* Presl) decreased rapidly in response to the massive applications of N. In 1969, the first year after application, none of the rates of applied N affected the frequency of Sandberg bluegrass. However, in the 3 subsequent years, all rates of applied N reduced the frequency of Sandberg bluegrass an average of 40 percentage points below the 47% frequency found on the untreated control. This represented an average decrease in plant density of about 88%.

Junegrass (*Koeleria cristata* (L.) Pers.) was nearly eliminated by all rates of N. In 1969, all treatments average about 35% frequency. In 1970 through 1972, all N treatments reduced frequency of Junegrass to 1 to 2% as compared with the average frequency of 40% on the untreated control.

Geyer larkspur (*Delphinium geyeri* Greene), a poisonous perennial plant, was abundant on the experimental site. Mean frequency percentages by year of sampling and N rates were as follows:

Year	0	224	448	672
1969	51	70	80	80
1970	67	82	90	79
1971	69	80	95	81
1972	67	78	90	72

Significant increases in frequency were found for all N treatments each year during the study.

Three other perennial forb species were common on the experimental area. None are important forage species. Milkvetch, a legume tentatively identified as either *Astragalus shortianus* Nutt. or *A. missouriensis* Nutt., was reduced to trace amounts in 1972 by all N treatments. Another legume, showy peavine (*Lathyrus polymorphus* Nutt.), was essentially eliminated by the N treatments. Generally, we would not expect legumes to respond favorably to massive N fertilization. The third species, Hood's phlox (*Phlox hoodii* Richn.), also was reduced to trace amounts by the N treatments.

The annual forb prairie pepperweed (*Lepidium densiflorum* Shrad.) greatly increased with all rates of applied N. Mean frequency percentages by years and N treatments were as follows:

Year	0	224	448	672
1969	2	7	5	6
1970	5	54	55	57
1971	75	99	99	96
1972	11	50	38	44

Plant density of prairie pepperweed increased about 16-fold in 1970, 3-fold in 1971, and 5-fold in 1972 as a result of the N treatments. This species was very abundant on all plots in 1971. Because of its accumulation of nitrate-N and potential toxicity to livestock (Houston et al., 1973), this species is undesirable.

Another potential problem species is slimleaf goosefoot, an annual forb that also concentrates nitrate-N (Houston et al., 1973). Mean frequency percentages were as follows:

Year	0	224	448	672
1969	3	24	16	28
1970	18	90	95	93
1971	7	23	27	34
1972	T	2	3	7

Slimleaf goosefoot increased greatly on all fertilized plots. It was far more frequent in the first 3 years than in 1972. The N treatments increased density of slimleaf goosefoot 9-fold in 1969, 14-fold in 1970, and 5-fold in 1971. This species is easily controlled with herbicide (Houston and van der Sluijs, 1973a).

Annual cheatgrass (*Bromus tectorum* L.) was significantly increased by applied N only during the last year of study. Frequency of cheatgrass brome was one percent or less on all plots during the first three years after massive N fertilization. Frequency increased up to 6 to 17% frequency on fertilized plots in 1972, while several of the dominant perennial species such as blue grama decreased.

In Montana, fringed sagewort (*Artemisia frigida* Willd.) initially increased in yield and then decreased after applications of 112 to 1,008 kg N/ha (Wight and Black, 1972). We also found that this species was susceptible to massive rates of N. Starting in 1970, all rates of N substantially reduced frequency of fringed sagewort. All rates of N reduced fringed sagewort to about the same level each year. Average reduction in frequency was 14 percentage points below the average frequency of 17% found on the untreated control. This was equivalent to about an 85% reduction in plant density.

Discussion and Conclusions

Massive applications of N fertilizer affect several different components of the rangeland ecosystem. The primary purpose of this study was to determine whether massive N applications were feasible for increasing forage yields and improving botanical composition on mixed-grass rangeland.

Application of N increased total herbage yields 53 to 87% over 4 years. Increases were greatest in 1970 or 1971, depending on rate of N applied. The 224 kg N increased yields an average of 8.4 kg for each kg of N. Substantial residual increases in yield might be expected as long as the increased density of western wheatgrass continues, or for a probable minimum period of 6 to 10 years after the single applications of N.

Applications of N substantially increased both the N content of herbage and yield of N. These represent valuable increases in nutritive value of herbage. Increased N content of herbage and increased yield of N both reached peaks in 1970 to 1971 and then decreased. Substantial residual increases in forage nutritive value might be expected for several years.

Amount of N accounted for in herbage and in soil mineral-N decreased substantially in early 1973, after four growing seasons, as compared with that accounted for in 1970, after two growing seasons. For all N applications, 55-77% of the applied N was accounted for in 1973, leaving 100 to 200 kg of N not accounted for and presumably immobilized in soil organic matter, grass roots, and fixed ammonium or lost by volatilization and leaching. This compares closely with the 60% of N accounted for by Power (1972) in North Dakota 4 years after applications of N up to 540 kg N per ha. The large concentration of soil mineral-N found between 60- and 90-cm depths in 1973 may be below the level of main root use. This suggests that this store of soil N will be little used in the future.

Desirable changes in species composition from the massive applications of N were the increase in western wheatgrass and the decrease in fringed sagewort. Reduced densities of blue grama and needleandthread were undesirable. Both species have high forage value. However, their loss may be compensated by the increase in western wheatgrass.

The increase in poisonous geyer larkspur from application of N was definitely undesirable. Livestock losses from this species can be catastrophic. This species can be controlled by herbicide (Alley and Lee, 1971; Hyder, 1972).

The increases in prairie pepperweed and slimleaf goosefoot were undesirable. Both species can concentrate nitrate-N to potentially toxic levels (Houston et al., 1973). These species also may be controlled with herbicide (Houston and van der Sluijs, 1973a).

The 100 to 200 kg of N/acre that apparently disappeared in the soil may not be lost. If immobilized in plant roots, the N will remain available for plant growth in future years. However, if the immobilized N was lost largely by leaching or by volatilization from the soil, then it is gone from the system.

The downward movement and concentration of mineral-N below the active root zone; increases in geyer larkspur, prairie pepperweed, and slimleaf goosefoot; and decreases in blue grama, needleandthread, Sandberg bluegrass, and Junegrass were all undesirable responses.

On this rangeland, massive applications of N are probably not practical.

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