High Rates of Nitrogen Change Composition of Shortgrass Rangeland in Southeastern Wyoming

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Highlight: High rates of nitrogen applied at one time or over a 4-year period markedly changed the botanical composition of shortgrass range. Blue grama and buffalograss cover declined and western wheatgrass increased. Total yields were significantly increased, largely because of the increase of annual forbs. Thus the only desirable change in the composition resulting from the high N application was the increase of western wheatgrass. Over the 5-year period, the NO_3-N accumulated in the 12- to 24-inch soil depth, whereas the grass roots were concentrated in the top foot of soil. The high rates of N increased crude protein significantly, thereby enhancing the palatability of the forage. Forbs on the high N plots were searched out and readily grazed by the sheep. Crude protein content was higher in the forbs than in the grasses in the fall. This study shows that high N rates applied either at one time or in yearly applications are neither economical nor practical because of the shift in the composition to undesirable annual forbs and slow recovery by the perennial grasses. The 150-lb N/acre rate applied once might be considered more practical than the other rates used in this study. Over the 5-year period this N rate produced 1,705 lb more total herbage than the check or 11.4 lb of herbage/lb of N. Neither the yield nor the crude protein increase was large enough to justify nitrogen fertilization of this range as an economic practice.

Forage production on rangeland is largely determined by the plant-soil-range condition and climate. Nitrogen (N) fertilization increases herbage production on some sites. A review of the literature by Lorenz and Rogler (1973) indicated that single applications of less than 30 lb N/acre did not significantly increase dry matter production, but that rates greater than 60 lb/acre usually did. Ford and Siddoway (1971) found that initial applications of 100 to 200 lb N/acre were required for the native range sites studied in northeastern Montana to reach their maximum productivity.

However, N fertilization can change the botanical composition of rangelands. Rauzi et al. (1968) found that with above-average precipitation, forbs and annual grasses accounted for more than 40% of the total herbage on plots fertilized with 33 and 66 lb N/acre 2 and 3 years after application in southeastern Wyoming. On a mixed prairie-type range in Alberta, Canada, the composition of the vegetation was markedly changed by the application of 772 or 975 lb/acre. Death of some native species from the high N rates resulted in bare ground that was invaded by weedy species (Johnston et al. 1967). Hyder and Bement (1972) also found that annual forb populations increased as a result of fertilization of shortgrass plains of northcentral Colorado. Russian thistle (*Salsola kali*) and slim leaf goosefoot (*Chenopodium leptophyllum*) increased after foliar application of urea on shortgrass range in northcentral Colorado (Houston and Van Der Sluijs 1973). Dwyer (1971) found that the production of forbs was not significantly affected by the addition of 40 lb N/acre in southcentral New Mexico. Houston and Hyder (1975) stated that high rates of N (191,403, and 604 lb/acre) decreased the density of some desirable plants and increased that of several undesirable ones.

Applications of high rates of N (600 to 1,000 lb N/acre) on rangelands were first investigated by Johnston et al. (1967) and Choriki et al. (1968). These rates affected the composition drastically: annual forbs increased and perennial grasses decreased. Also, some forbs concentrated nitrate to toxic levels.

Power (1970) found that application of 480 lb N/acre immediately established a large pool of NO_3-N in the soil. Most of the fertilizer not used in one season was carried over in mineral form to the next season. Thus Power (1970) concluded that most fertilizer applied in excess of that required by the vegetation under semiarid conditions remains in the root zone until it is absorbed by the roots and translocated to new growth. The N-immobilizing capacity of a given system may vary somewhat with soil texture, vegetation, and other parameters (Power 1972).

This paper discusses the effects of high rates of N fertilization of shortgrass rangeland, loamy range site in southeastern Wyoming. High N rates are considered as more than 100 lb per acre and low rates, as 100 lb or less per acre.

Methods

The study area was in southeastern Wyoming at the Archer Substation about 10 miles east of Cheyenne. The elevation is about 6,100 ft. The dominant species are blue grama (*Bouteloua gracilis*), buffalograss (*Buchloe dactyloides*), and western wheatgrass (*Agropyron smithii*). Annual grasses and forbs were present in varying amounts. Soil on the experimental area was Archerson fine sandy loam, a member of the mixed, mesic family of Aridic Argiustolls. Archerson soils are on nearly level to gently sloping fans and terraces of granitic origin containing Arkosic sand and gravel and are noncalcareous to 24 inches and calcareous from 24 to 60 inches. Texture, pH, organic matter content and sodium-bicarbonate-extractable phospho-

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rus for the 0- to 6-inch and 6- to 12-inch soil depth, were respectively loam, 6.3, 2.7% and 16 lb/acre and sandy clay loam, 6.9, 1.7% and 4 lb/acre.

In March 1970, plots 10 by 50 ft were established on native rangeland. The experimental design was a randomized complete block with four treatments and three reapplications. Ammonium-nitrate was applied once at rates of 0, 150, and 600 lb N/acre and a fourth treatment of 150 lb N/acre applied annually for 4 years. All fertilizer was applied in March with a 5-ft spreader.

Each spring (1970 through 1974) three subplots 4 ft^2 (14.3 by 40.3 inches) were randomly located in each plot, and the previous year's vegetation was removed before plant growth started. Herbage in the subplots was harvested at ground level in mid-August or early September by major species. Annual grasses, forbs, and Sandberg bluegrass matured earlier and a large part of this production was lost before harvest. After the subplots were harvested, the experimental area was grazed by sheep.

Air-dry herbage yields were determined for the major grass species, dryland sedges, and total herbage. Herbage yields were statistically analyzed and Duncan's multiple range test for significance was applied at the 5% probability level. Botanical composition was determined by weight.

Each fall (1970 through 1974) four soil cores 4.20 cm in diameter were obtained from the 0- to 6-inch and 6- to 12-inch depths from each plot. The soil cores were oven dried at 105°C for 48 hours, and the soil was then washed from the root biomass. All organic material that floated and root material were collected and thoroughly washed, oven dried at 70°C for 24 hours, weighed, and analyzed for total N.

The plant and root material of the major species was ground in a Wiley mill to pass 40-mesh openings. Total plant N was determined by the Kjeldahl method and crude protein was calculated (%N by 6.25).

Three soil samples each from the 0- to 6-, 6- to 12-, and 12- to 24-inch depths were obtained in April and again in late August or early September to determine soil water content. In September 1974 three soil samples were obtained from the 0- to 6-, 6- to 12-, 12- to 24-, and 24-to 36-inch depths from all main plots and open dried at 55°C for 15 hours. These soil samples were analyzed for NO_3-N using a NO_3-specific ion electrode.

Results and Discussion

Herbage Yields

Yields of major grass species, total grass plus sedges, and total herbage varied with years and treatments (Table 1). Nitrogen treatments significantly increased the average 5-year yields (1970–1974) of western wheatgrass and blue grama. However, the average yield for blue grama is misleading because yields declined dramatically the last 3 years of the study, particularly on plots receiving 600 lb N/acre in one application. Average mean yields of buffalograss were significantly reduced by the N treatments, whereas those of dryland sedges were not affected. Total grass plus sedges yield and total herbage yield were both significantly increased by N treatments. Yields of total grass and sedges declined the last 3 years of the study on all N treatments. In 1972, 1973, and 1974, annual forbs accounted for nearly half of the total herbage on the treatment that received 600 lb N/acre and less than 3% of the total herbage on check plots.

Table 1. Yields (lb/acre) of western wheatgrass, blue grama, buffalograss, dryland sedges, total grass, and total herbage from fertilized and nonfertilized shortgrass rangeland. Archer Substation, Cheyenne, Wyo., 1970–1974.

Year	Check	150lb N/acre[1]	150 lb N/acre[2] 4-years	600 lb N/acre[1]	Year mean
			Western wheatgrass		
1970	62^{a}	132^{a}	166^{a}	148^{a}	127^{a}[3]
1971	85^{c}	318^{ab}	177^{abc}	370^{a}	237^{a}
1972	31^{a}	83^{a}	142^{a}	165^{a}	105^{a}
1973	76^{c}	175^{b}	171^{bc}	408^{a}	208^{a}
1974	113^{a}	198^{a}	218^{a}	204^{a}	183^{a}
Mean	73^{c}	181^{b}	175^{b}	259^{a}	
			Blue grama		
1970	349^{b}	721^{ab}	577^{ab}	739^{a}	596^{a}
1971	309^{c}	394^{bc}	473^{b}	630^{a}	451^{b}
1972	308^{b}	361^{a}	390^{a}	271^{a}	332^{b}
1973	365^{a}	469^{a}	580^{a}	389^{a}	451^{b}
1974	381^{a}	329^{a}	218^{a}	99^{b}	257^{c}
Mean	342^{b}	455^{a}	448^{a}	426^{a}	
			Buffalograss		
1970	90^{a}	85^{a}	111^{a}	66^{a}	88^{a}
1971	182^{a}	124^{a}	92^{a}	76^{a}	118^{a}
1972	103	34	22	24	46^{b}
1973	171^{a}	138^{a}	36^{a}	8^{a}	88^{a}
1974	147	82	2	5	59^{a}
Mean	139^{a}	93^{b}	53^{c}	36^{c}	
			Dryland sedges		
1970	58^{a}	80^{a}	74^{a}	74^{a}	71^{a}
1971	68^{a}	95^{a}	126^{a}	110^{a}	100^{a}
1972	45^{a}	95^{a}	122^{a}	80^{a}	85^{a}
1973	97^{a}	141^{a}	72^{a}	111^{a}	105^{a}
1974	77^{a}	101^{a}	77^{a}	84^{a}	85^{a}
Mean	69^{a}	102^{a}	94^{a}	92^{a}	
			Total grass and sedges		
1970	560^{b}	1020^{a}	932^{ab}	1028^{a}	885^{a}
1971	647^{c}	1022^{ab}	896^{bc}	1240^{a}	951^{a}
1972	492^{a}	575^{a}	670^{a}	468^{a}	551^{c}
1973	711^{a}	926^{a}	806^{a}	915^{a}	839^{b}
1974	735^{a}	764^{a}	559^{a}	393^{a}	613^{c}
Mean	629^{c}	861^{a}	773^{b}	809^{ab}	
			Forbs		
1970	15^{a}	25^{a}	60^{a}	63^{a}	41^{d}
1971	10^{a}	80^{a}	20^{a}	297^{a}	102^{c}
1972	11^{c}	53^{c}	265^{b}	507^{a}	209^{b}
1973	10^{c}	96^{c}	587^{b}	889^{a}	395^{a}
1974	43^{b}	97^{b}	362^{a}	320^{a}	205^{b}
Mean	18^{c}	70^{c}	259^{b}	415^{a}	
			Total herbage		
1970	575^{b}	1280^{a}	970^{ab}	1090^{a}	979^{b}
1971	658^{c}	1102^{b}	961^{b}	1537^{a}	1064^{b}
1972	503^{c}	648^{b}	936^{ab}	1065^{a}	788^{c}
1973	718^{d}	1044^{c}	1695^{ab}	1841^{a}	1324^{a}
1974	778^{a}	860^{a}	921^{a}	713^{a}	818^{c}
Mean	646^{c}	987^{b}	1097^{ab}	1249^{a}	

[1] Nitrogen applied once in March 1970.
[2] Nitrogen applied at the rate of 150 lb/acre in March 1970, 1971, 1972, and 1973.
[3] Means within columns among treatments and years with the same letters are not significantly different at the 5% level according to Duncan's multiple range test.

The decline in blue grama and buffalograss and the increase in annual grasses and forbs may be related to the dry, open winter in 1971 and 1972 coupled with high winds that dried the surface soil. Reduction of the grass density left a void filled by annual forbs, particularly slim leaf goosefoot and field pennycress (*Thalapsis arvense*). In 1972, 1973, and 1974, plots treated with either 600 lb N/acre applied once or 150 lb N/acre applied each year for 4 years had a solid stand of either slim leaf goosefoot or field pennycress. During the first 2 years of

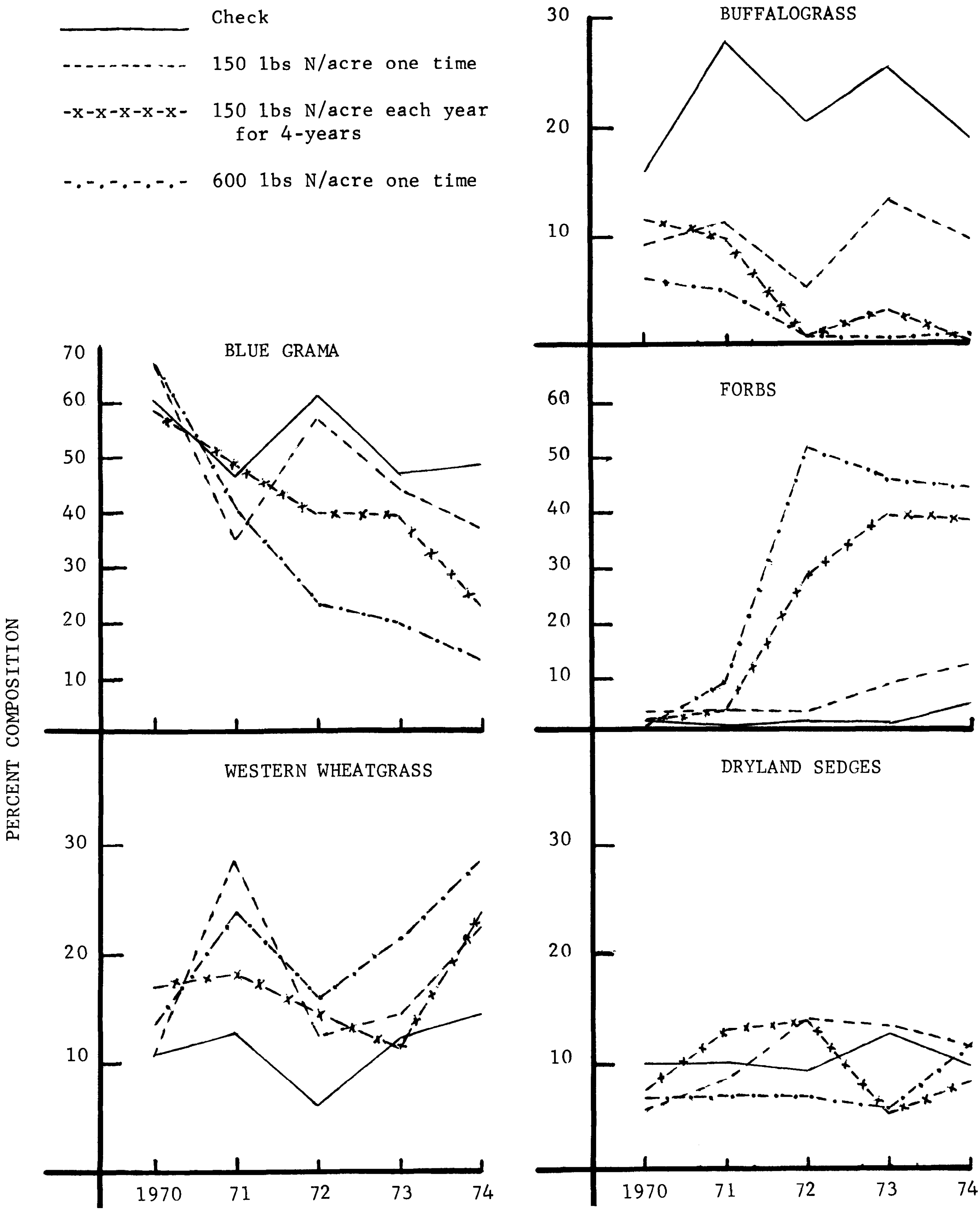

Fig. 1. *Percentage composition by weight over a 5-year period from shortgrass rangeland fertilized with 0, 150, and 600 lb N/acre one time and 150 lb N/acre each year for 4 years (Archer Substation).*

the study, forbs were of little importance on all treatments. Yield of forbs, increased dramatically the next 2 years on the plots treated once with 600 lb N/acre and the plots treated with 150 lb N/acre annually for 4 years. Forb yield declined on these same high-N plots in 1974 because of limited precipitation in April and May. Even so, the forbs made up 45% of the total herbage on the plots treated once with 600 lb N/acre and 39% on the plots treated with 150 lb N/acre annually for 4 years.

Crude Protein

Crude protein in the harvested western wheatgrass and blue grama from all treatments was significantly increased by the N treatments. Significant differences between years in crude protein content of western wheatgrass and blue grama seem to be due to the amount and distribution of precipitation. Crude protein content was lowest in 1970 and highest in 1973; April-May-June precipitation in 1973 was less than half that received in 1970.

Average crude protein of western wheatgrass and blue grama was increased 24 and 37% over the check by 150 lb N/acre applied annually, and 58 and 72% by 600 lb N/acre applied once. Thus the two high N rates increased crude protein in the plant material, enhancing herbage quality.

Composition

Botanical composition of the vegetation on each plot was determined by weighing separated and direct herbage harvested from the subplots. Vegetative composition was influenced by N treatment and by the prevailing weather. The proportion of total herbage contributed by blue grama decreased and western wheatgrass increased on all treatments over the 5-year period. On the plots treated once with 600 lb N/acre (Fig. 1) blue grama decreased from 68% the first year to 14% the fifth year; western wheatgrass increased from 13% the first year to 29% the last year of the study. Decreases in blue grama and increases in western wheatgrass were common to all treatments but were most drastic for the 600 lb N/acre treatments.

Forbs and annual grasses were of minor importance on the check and the plots treated once with 150 lb N/acre. However, they increased from 4% the first year to 44% the fifth year on plots treated with 150 lb N/acre annually and from 6% to 45% on plots treated once with 600 lb N/acre.

Buffalograss on the two high N treatments decreased from an average of 9% the first year to a trace by the fifth year of the study. Apparently, buffalograss does not tolerate high N fertilization.

Nitrate Concentration in the Soil

Nitrate-N in the soil was determined at the end of the study on September 10, 1974. Over the 5-year period (1970-1974) NO_3-N moved downard in the soil profile, with the greatest accumulation from the high N rates in the 12- to 24-inch soil depth (Fig. 2). For the 150 lb N/acre applied each year for 4 years, accumulation of NO_3-N in the 24- to 36-inch soil depth was less than half of that in the 12- to 24-inch soil depth. Twice as much NO_3-N had accumulated in the 24- to 36-inch soil depth from the 600 lb N/acre applied one time compared to 150 lb N/acre applied annually for 4 years. Above-normal rains in late July (4.03 inches) and early September (4.48 inches) 1973 may have caused NO_3-N to move deeper into the profile than is normal at this location.

Root Biomass

Total N in the root biomass did not differ significantly between treatments over the 5-year period at either the 0- to 6- or 6- to 12-inch soil depth. The average amounts of total N in the root biomass for the four treatments were 1.26 and 1.22% for the 0- to 6- and 6- to 12-inch soil depths, respectively.

The average weight of the root biomass in the 0- to 6-inch soil depth was not significantly different between treatments. In the 6- to 12-inch soil depth, significantly more root biomass was obtained from the 600 lb N/acre treatment applied once than from the 150 lb N/acre treatment applied one time or annually for 4-years. There was no significant difference in the amount of root biomass between the check and the other three treatments. On a per acre basis, over all treatments, root biomass averaged 21,000 lb/acre in the 0- to 6-inch depth and 6,900 lb/acre in the 6- to

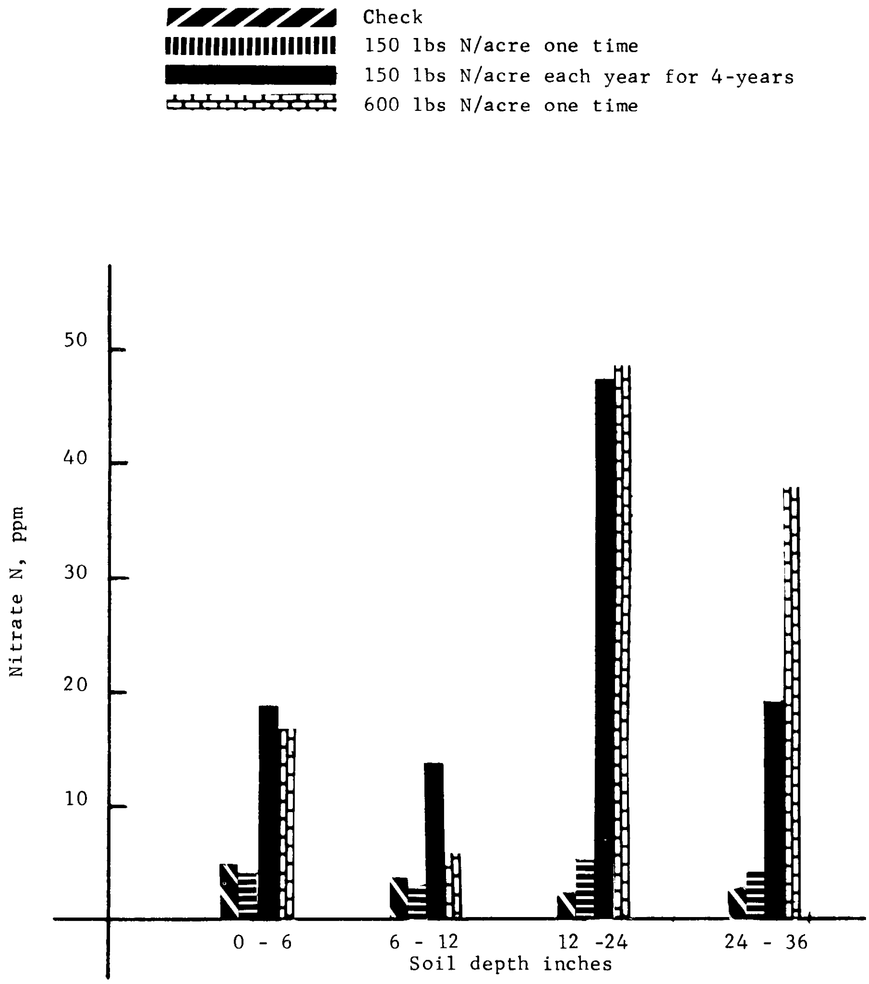

Fig. 2. *Nitrate-N concentration in the soil profile (Archer Substation) September 1974.*

Table 2. Annual April through September, and April, May, and June precipitation (inches) for the 1970–1974 period, and the 54-year average at the Archer Substation, Wyo.

Year	Annual	April through September	April	May	June	Total
1970	15.4	11.3	1.5	2.7	3.2	7.3
1971	13.1	9.9	2.9	2.7	1.0	6.7
1972	14.8	11.9	1.4	1.4	4.0	6.8
1973	18.5	11.5	1.8	.6	1.1	3.6
1974	11.6	7.7	1.2	.3	3.1	4.6
5-year avg.	14.7	10.5	1.8	1.5	2.5	5.8
54-year avg.	14.7	11.4	1.5	2.5	2.5	6.6

12-inch soil depth. This amount of root material represents an average of 265 lb N/acre in the 0- to 6-inch soil depth and 84 lb N/acre in the 6- to 12-inch soil depth. Power and Alessi (1971) found 23,800 lb/acre of root material on a loamy range site in the top 12-inches of soil, while Wight (1976) found 18,000 lb/acre on a sandy upland range site in Montana.

Precipitation and Evapotranspiration

Distributions and amounts of annual, seasonal, and April-May-June precipitations were erratic and influenced the herbage yield and vegetative composition (Table 2). The April-May-June precipitation was 12% above the 54-year average in 1970, but it was 45% below the long-time average in 1973. Precipitation during April and May 1972, was light and of little value for plant growth, whereas the June precipitation of 4.03 inches was responsible for most of the plant growth. Annual precipitation was highest in 1973, with 4.48 inches of rain received during September. Most of the winter precipitation was received during October, November, and March and generally contributed little to the soil water except where snow was trapped or drifted. The winter of 1971-1972 was dry and open, with high winds that dessicated the surface soils. Late spring snowstorms in 1973 and 1974, accompanied by high winds that caused irregular drifting, resulted in variable amounts of water entering the soil.

Differences between average soil water content in April and again in either August or September plus the precipitation from events greater than 0.10 inch were considered evapotranspiration. Average evapotranspiration for 1971 through 1974 was 9.1, 9.3, 8.7, and 9.1 inches for the check, 150 lb N/acre applied one time, 150 lb N/acre applied annually for 4 years and 600 lb N/acre applied one time. Thus the overall average evapotanspiration during the growing season was 9.0 inches. The most soil water was available and used in all evapotranspiration during 1973, and the least, in 1971. By early fall nearly all the water in the upper 2 feet of soil was exhausted. Rains in late August and September were of little value for plant growth but did aid in recharging the soil profile.

Water-efficiency for each treatment was determined by dividing total water used into average total herbage produced. The high N-plots had the highest water-use efficiency, mostly because of the greater amount of annual forbs. However, water-use efficiency dropped sharply if only the total grass and sedges were considered. Water-use efficiency was highest for plots receiving 150 lb N/acre each year for 4 years and lowest for the check.

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