Nitrogen and Phosphorus Availability in a Fertilized Rangeland Ecosystem of the Northern Great Plains[1]

A. L. BLACK AND J. ROSS WIGHT

Soil Scientist and Range Scientist, Respectively, U.S. Department of Agriculture, Sidney, Montana.

Highlight

Factorial combinations of ammonium nitrate at rates of 0, 100, 300, and 900 lb. N/acre and concentrated superphosphate at rates of 0, 100, and 200 lb. P/acre were broadcast on a native range site (a *Bouteloua-Carex-*[*Stipa*] faciation of a mixed prairie association) near Sidney, Montana. In 2 years, the addition of a high rate of N and P fertilizer increased total forage production 3.3-fold, total crude protein 6.7-fold, and plant N and P percentages about 2.0-fold. High rates of N applied alone had no marked effect on plant P percentage the year of application, but plant P percentage was reduced nearly 2.0-fold the second year by all rates of N. Nitrate-nitrogen was concentrated in the upper 3 feet of soil in 1969 and in the upper 5 feet of soil in 1970. Nearly all of the P fertilizer applied was concentrated in the upper 3 inches of soil in 1969 and in the upper 6 inches of soil in 1970. The high rate of N applied alone decreased soil pH from about 6.9 to 6.1 in the 0- to 6-inch soil depth in 1969 and from 6.9 to 6.5 in 1970 even though the soil was strongly calcareous.

Forage production on rangeland is governed by plant-soil-climate relationships. Nutrient content of forage, within individual plant species, is dependent on soil fertility and the rate of release of soil nutrients. In the northern Great Plains, cycling and availability of nutrients to plants are controlled largely by climatic factors—primarily soil temperature and available soil water. The effects of high fertilization and other range management techniques on nutrient cycling and availability, and their interaction with climatic factors, have not been fully determined.

The significance of N and P fertilizer interactions on availability of soil N and P, and subsequent plant growth and nutrient uptake, becomes increasingly important when fertilizer materials are applied at high rates. The objectives of this paper are to consider these interactions in relation to the N and P content of range plants.

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Materials and Methods

Details of the study site, experimental design, fertilizer treatments, and harvest methods are given in a preceding paper by Wight and Black (1972). In brief, the experiment was a randomized block, split-plot design with P fertilizer rates of 0, 112, and 224 kg/ha (0, 100, and 200 lb./acre) as main plots and N fertilizer rates of 0, 112, 336, and 1008 kg/ha (0, 100, 300, and 900 lb./acre) as subplots. The respective sources of N and P were ammonium nitrate and concentrated superphosphate.

Plant samples were obtained by hand clipping one 0.25- by 4-m (0.8- by 13.1-foot) quadrat per plot at ground level. Harvested plants were separated by species, ovendried at 65 C, and ground for chemical analysis. For discussion purposes in this paper, plant species were grouped into two categories: Grasses—western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), prairie junegrass (*Koeleria cristata*), and needleandthread (*Stipa comata*); and nongrasses—threadleaf sedge (*Carex filifolia*) and other sedges, goatsbeard (*Tragopogon dubius*) and other forbs, and fringed sagebrush (*Artemisia frigida*) and other shrubs.

Plant N was determined by the Kjeldahl method, modified to exclude plant nitrates (Jackson, 1958); and crude protein was calculated (% N × 6.25 = % crude protein). Plant P was determined colorimetrically (Barton, 1948) following wet oxidation of plant tissues. All significant differences in plant N and P content discussed are at the P = .05 level, unless otherwise indicated.

Before initial fertilization in the spring of 1969, soil samples were obtained by genetic horizons and various chemical and physical soil properties were determined. In the fall of 1969 and 1970, soil samples were also taken from selected fertilizer plots at the following depth increments: 0 to 7.5, 7.5 to 15, 15 to 30 cm, and by 30-cm-depth increments to 244 cm (8 ft). Available P was estimated by the $NaHCO_3$ method (Olsen et al., 1954). Organic matter percentage was determined by the Walkley-Black procedure; pH, by glass-calomel electrodes in 1:1 soil-to-water pastes; NO_3-N, by the phenoldisulfonic acid procedure; and total soil N, by the Kjeldahl procedure (Jackson, 1958). Percentages of sand, silt, and clay were determined by the hydrometer method.

Table 1. Some chemical properties of Sprole loam range site.

Horizon	Soil depth (cm)	Texture*	pH	Organic matter (%)	Total N (%)	NO_3-N (ppm)	$NaHCO_3$-soluble P (ppm)
A1	0– 11	SL	6.8	2.50	.133	7.9	1.8
B2	11– 25	SClL	6.9	1.67	.104	0.8	0.3
B3ca	25– 36	ClL	8.1	2.27	.143	1.3	0.4
C1ca	36– 46	ClL	8.3	1.60	.098	1.3	0.2
C2ca	46– 76	L	8.5	0.94	.059	0.8	0.5
C3	76– 91	L	8.6	0.60	.035	1.3	0.5
C4	91–119	SL	8.8	0.47	.029	0.8	1.7
C5	119–132	SL	8.4	0.50	.024	0.8	1.2

* SL = Sandy Loam; SClL = Sandy Clay Loam; L = Loam.

Results and Discussion

Results of soil analysis of the samples obtained by genetic horizon prior to fertilization are shown in Table 1. From the B horizons downward, the glacial till soil increases in soil particle size, with the quantity of small and large gravel increasing progressively with depth. Organic matter and total N percentages decreased sharply with profile depth below 46 cm (18 inches). Soil pH increased sharply in the 25- to 36-cm (10- to 14-inch) soil depth which coincided with the beginning of the zone of high lime content. In general, the soil profile is highly calcareous and deficient in available N and P. Soil NO_3-N and $NaHCO_3$-soluble P decreased to an extremely low level below the first 11 cm (4.5 inches). Available P increased slightly in the 91- to 132-cm (36- to 52-inch) depth.

At the end of the first and second growing seasons, soil NO_3-N, pH, and $NaHCO_3$-soluble P were determined by selected increments to a depth of 244 cm in selected fertilizer plots. Soil NO_3-N was determined in plots receiving 0, 112, 336, and 1008 kg/ha of N applied alone. Profile distribution and total soil NO_3-N for these fertilizer plots are shown in Table 2. Check plots in the fall of 1969 and 1970 had very low levels of soil NO_3-N, totaling 29 and 27 kg/ha (26 and 24 lb./acre), respectively. Total soil NO_3-N increased about 55 kg/ha (50 lb./acre) for each 112 kg/ha (100 lb./acre) of N applied, and the amount present was about the same at the end of both growing seasons. Since one-half of the N applied was in ammonium form, it had to undergo nitrification before it could be measured in nitrate form. In either year, only 50 to 70% of the added N was measured as nitrate. In 1969, considerable quantities of added N (30 to 50%) were probably immobilized in the organic phase or present in other forms of N. Added N may have stimulated N mineralization from organic sources in this severely N-deficient soil by the second year, which may explain why soil NO_3-N was higher in the fall of 1970 than in the fall of 1969, despite plant N uptake for two seasons.

Soil NO_3-N was distributed throughout the profile to a depth of 244 cm with the two highest rates of N. However, most of the NO_3-N was concentrated in the upper 91 cm (3 ft) in 1969 and in the upper 152 cm (5 ft) in 1970. Above-average April–May precipitation in 1970 caused soil NO_3-N to move deeper into the profile than ordinarily would be expected on rangeland in the northern Great Plains.

Soil pH was determined in check

Table 2. Profile distribution and total soil nitrates (ppm) at the end of the 1969 and 1970 growing season as influenced by high N fertilization (kg/ha).

Soil depth (cm)	Nitrogen added 0		112		336		1008	
	1969	1970	1969	1970	1969	1970	1969	1970
0– 7.5	1.3	1.4	1.3	1.5	8.8	7.5	57.0	17.2
7.5– 15	1.2	1.1	1.2	1.3	5.4	8.1	50.5	27.2
15– 30	1.1	1.0	1.9	1.3	10.2	5.2	25.7	11.6
30– 61	1.0	1.0	1.9	1.6	19.4	12.3	62.5	20.0
61– 91	1.0	0.8	2.0	4.5	6.6	15.1	13.8	12.2
91–122	0.9	1.0	1.7	5.0	5.8	12.5	5.0	52.0
122–152	0.9	0.5	1.4	1.8	2.5	8.1	1.9	20.9
152–183	0.5	0.5	1.4	1.7	2.1	2.4	1.4	8.0
183–213	0.5	0.5	1.0	1.0	1.5	1.6	1.0	1.4
213–244	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0
Total NO_3-N (kg/ha)	29	27	52	78	210	283	566	594

Table 3. Soil pH in 1969 and 1970 and $NaHCO_3$-soluble P (ppm) in 1969 in the profile as influenced by high N and P fertilization.

Soil depth (cm)	Soil pH				$NaHCO_3$-soluble P		
	1969		1970		1969		
	0–0*	1008–0	0–0	1008–0	0–0	1008–0	1008–224
0– 7.5	6.8	6.2	6.9	6.5	1.5	2.6	44.8
7.5– 15	6.9	6.0	7.0	6.8	0.5	1.0	16.0
15– 30	8.1	7.8	7.9	7.8	0.3	0.4	2.1
30– 61	8.3	8.1	8.1	8.0	0.3	0.3	1.0
61– 91	8.5	8.4	8.5	8.4	0.5	0.5	0.6
91–122	8.8	8.7	8.8	8.7	1.5	1.4	1.2
122–152	8.5	8.5	8.6	8.6	1.4	1.3	1.4
152–183	8.5	8.5	8.4	8.3	0.2	0.3	0.3
183–213	8.3	8.4	8.3	8.4	0.3	0.2	0.2
213–244	8.4	8.4	8.4	8.4	0.3	0.3	0.3

* kg/ha of N and P applied, respectively.

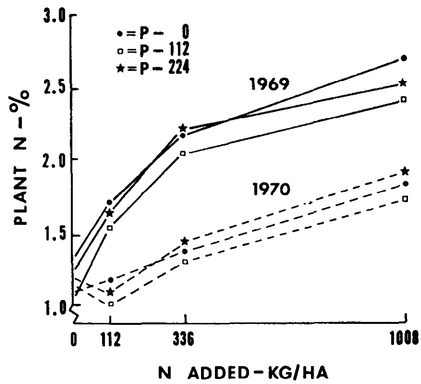

FIG. 1. Average plant N percentage of grasses as influenced by high fertilization.

and high-N plots in the fall of 1969 and 1970 (Table 3). In both years, pH was reduced considerably in the 0- to 7.5- and 7.5- to 15-cm (0- to 3- and 3- to 6-inch) depths by N applied at the high rate. Although not shown in Table 3, the 336-kg/ha (300-lb./acre) rate of N caused a proportionate one-third of the decrease shown for the high N rate. Inasmuch as the zone of high lime accumulation began at about the 30-cm (12-inch) depth, changes in pH below this depth were minimal. Soil pH increased in the zones above 30 cm (12 inches) between 1969 and 1970 on the high-N plot as would be expected because of the relatively high buffering capacity of calcareous soils. The first-year change in pH from the high rate of N fertilization in this study was similar to that reported by Smika et al. (1961) for nine annual applications of N at a rate of 101 kg of N/ha (90 lb. of N/acre).

Soluble P was increased several-fold by P fertilization, but the increase was limited primarily to the top 15 cm of the soil profile (Table 3). Small increases in soluble P were detected in the 15- to 30- and 30- to 61-cm (6- to 12- and 12- to 24-inch) depths. High application rates of P resulted in some movement of P into deeper soil layers making it more readily available to plants under semiarid conditions. In the upper 15 cm, soluble P in the high-N plot without P added was slightly higher than the check. The increase in soil pH associated with the high rate of N applied alone would be expected to increase soil P availability because the solubility of inorganic P sources in calcareous soils increases when soil pH decreases. However, the $NaHCO_3$ method failed to detect much of an increase in soluble P levels as a result of the high-N rate in the fall of 1969; yet plant P content and total P uptake increased nearly 2-fold.

Plant N Percentage

Since the influence of fertilizer treatments on plant N percentage was similar for individual species, data were averaged by years for grasses and nongrasses and are shown in Figures 1 and 2, respectively. In 1969, N applied at rates of 112, 336, and 1008 kg/ha increased N percentage of grasses 1.2-, 1.7-, and 2.0-fold, respectively, and 0-, 1.4-, and 1.7-fold, in 1970 (Fig. 1). Similar increases in plant N percentages were obtained for nongrasses (Fig. 2). Phosphorus applied alone or in combination with N had no influence on plant N percentages of grasses or nongrasses in either year.

In 1969 and 1970, total forage production increased about 1.7-, 2.8-, and 4.0-fold with applications of 112, 336, and 1008 kg/ha of N. These increases in total dry matter production, when combined with progressive increases in percent plant N, resulted in a 2.7-, 5.4-, and 6.7-fold increase in total production of crude protein. Over the 2-year period, the check plot produced only 177 kg/ha (158 lb./acre) of crude protein, compared with 736 kg/ha (657 lb./acre) produced with an application of 1008 kg/ha of N alone or 1190 kg/ha (1062 lb./acre) produced with the same rate of N applied in combination with P. Crude protein was not significantly influenced by P applied alone. When compared within the same level of added N, P increased total crude protein production about 30%.

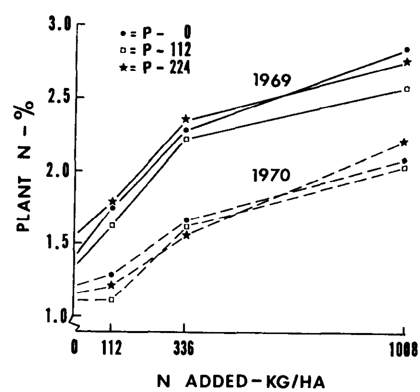

FIG. 2. Average plant N percentage of nongrasses as influenced by high fertilization.

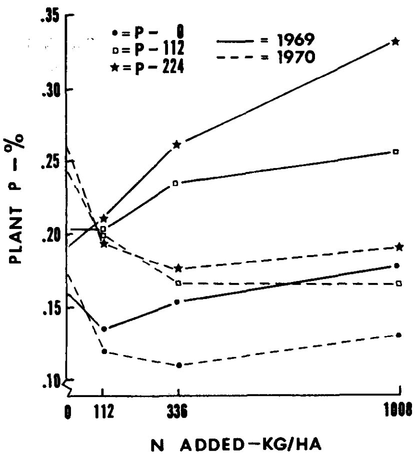

FIG. 3. Average plant P percentage of grasses as influenced by high fertilization.

Dee and Box (1967) found a positive effect of P fertilizer within N treatments on the crude protein level of several mixed prairie grasses. In this study, grasses alone accounted for only 25% of the total crude protein produced without fertilization in 1969 and 1970. With high N-P fertilization, grasses produced 50% of the total protein in 1969 and 80% in 1970.

Percent recovery of N applied at rates of 112, 336, and 1008 kg/ha was 42, 37, and 16% with P added, and 30, 22, and 9% without P, respectively. Although efficiency of N recovery decreased with increasing rate of N applied and N recovery percentages were low, similar results have been reported by other research workers in the northern Great Plains (Rogler and Lorenz, 1957; Smika, Haas, and Rogler, 1960; Smoliak, 1965; Cosper, Thomas, and Alsayegh, 1967; Black, 1968; and Johnston et al., 1968). These researchers have also observed the positive effect of P fertilization on the efficiency of N recovery.

Plant P Percentage

Average plant P percentage of grasses for 1969 and 1970 is shown in Fig. 3; nongrasses, in Fig. 4. In 1969, N applied alone at a rate of 112 kg/ha depressed P percentages of grasses and nongrasses, 336 kg/ha had no effect on P percentages, and 1008 kg/ha increased plant P percentages, compared with the unfertilized plot. The increase in plant P obtained the first year with the high-N rate is in contrast with other research (Smika et al., 1960; Cosper et al., 1967; and Black, 1968), where traditionally N applied alone has reduced percent plant P. The first-year decrease in pH may have increased the availability of soil P from native sources. However, the second year following application, all rates of N applied alone significantly reduced (P = .01) plant P percentage in both grasses and nongrasses. Without the addition of P fertilizer, plant P percentages in grasses and nongrasses fertilized with N alone were below the level of 0.17% P set by the National Research Council (1958) for a maintenance ration. With P added at either rate, plant P percentage was adequate in the grasses and more than adequate in nongrasses. In general, added P increased percent P proportionately more in nongrasses than in grasses.

High rates of N applied alone increased total forage P uptake 2-fold (data not shown); and when combined with either rate of P, high rates of N increased total P uptake 5- to 6-fold. In the presence of added N, about 10% of the fertilizer P applied was recovered in the aboveground plant material over the 2-year period. Phosphated plots should effectively increase plant P content for several years as reported previously by Black (1968) and Smoliak (1965).

In just 2 years, the addition of a high rate of N and P fertilizer increased total forage production 3.3-fold, total crude protein 6.7-fold, and plant N and P contents about 2-fold. Therefore, not only total forage production increased, but the quality of forage as well. Plant-soil systems of rangeland have a large proportion of the soil N and P required for plant growth tied up in the organic phase in relatively unavailable forms. This is

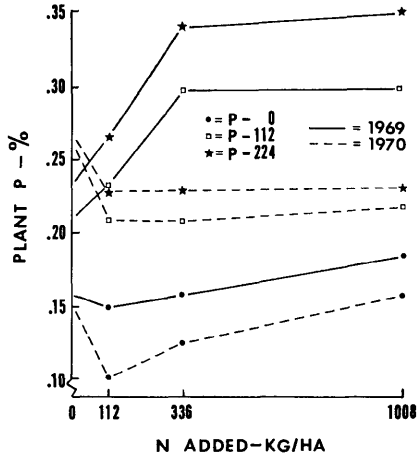

FIG. 4. Average plant P percentage of nongrasses as influenced by high fertilization.

corroborated by the low yield and low quality of unfertilized range plants in this study. The authors recognize that maximum forage yields may not be the most economical or desirable target. Nevertheless, at least 336 kg/ha of N and 112 kg/ha of P were required to obtain maximum forage yields and improve quality to adequate standards, while at the same time supplying the quantities of N and P needed to satisfy the nutrient-starved initial organic cycle and maintain an active final organic cycle.

In this study, plants growing on the high N-P fertilizer plots began growth earlier and grew faster in the spring of both years than plants growing on unfertilized soils. Power et al. (1963) have shown that high soil P levels reduced the sensitivity of plants to cool soil temperature. Nitrogen availability is equally important in stimulating early plant growth. Timely nutrient availability is an extremely important growth aspect in relation to efficient plant utilization of stored soil water and growing season precipitation in a relatively cool, semiarid climate.

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