Range Fertilization: Nitrogen and Phosphorus Uptake and Recovery Over Time

A.L. BLACK AND J. ROSS WIGHT

Abstract

Little information has been published concerning the long-term effects of N and P fertilization on nutrient cycling and availability of N and P as related to quantity and quality of native grassland herbage. Factorial combinations of ammonium nitrate at rates of 0, 112, 336, and 1,008 kg N/ha and concentrated superphosphate at rates of 0, 112, and 224 kg P/ha were broadcast once in the spring of 1969 on a native range site (*Bouteloua-Carex* [*Stipa*] faciation of a mixed prairie association). During the next 8-years, plant N and P content of grasses and nongrasses increased for periods of time proportionated to the rate of N and P applied. Plant N content tended to be low in "wet" years and relatively high in "dry" years. Conversely, plant P content tended to be high in "wet" years and relatively low in "dry" years. After the first 2 years, the increase in plant N and P uptake, resulting from a given level of N-P fertilization, continued at a rather stable rate as compared with the unfertilized check. In 1973, the unfertilized check had 20,700 kg/ha of root material in the upper 30 cm of soil. The fertilized (336 kg N/ha plus 224 kg P/ha) grassland had 24,310 kg/ha of root material which contained 116 kg/ha more N and 8 kg/ha more P than did the check. Therefore, the below-ground root system is a nutrient-deficient sink which has a high potential to immobilize relatively large quantities of applied N and P fertilizer materials. This study revealed the long-term benefits of N and P fertilization on forage quality which may persist for several years after yield responses are no longer apparent.

Authors are soil scientist and range scientist, respectively, U.S. Dep. Agr., Science and Education Administration, Agricultural Research, Northern Plains Soil and Water Research Center, P.O. Box 1109, Sidney, Montana 59270.

The study is a contribution from the U.S. Dep. Agr., SEA, and Montana Agricultural Experiment Station, Sidney, Montana, Journal Series No. 828.

Manuscript received July 10, 1978.

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. Availability of nitrogen (N) and phosphorus (P) influences both quantity and quality of the forage produced. The amount of water that becomes available for plant use and the efficiency with which it is used is greater in a fertilized than an unfertilized grassland ecosystem (Wight and Black 1978). Nitrogen fertilization usually increases the amount of water becoming available for plant use by increasing soil water extraction and overwinter recharge.

Our knowledge of N and P cycling has been increased considerably in recent years. Two recent reviews of range fertilization research in the northern Great Plains have been published (Rogler and Lorenz 1974; and Wight 1976). Power (1972) described the N-cycle of native grasslands and postulated that "nitrogen may be eliminated as a growth-limiting factor within a soil-plant system by providing sufficient inorganic N to completely saturate the capacity of the system to immobilize N, thereby setting up new equilibrium conditions whereby annual immobilization and irreversible losses are balanced by mineralization plus inorganic N additions."

Our knowledge of the P-cycle is not as complete for native grasslands as it is for the N-cycle. However, Cole et al. (1977) developed a P-flow simulation model based on field data and published research, which integrated the effects of soil properties, moisture, plant phenology, and microbial decomposition of organic matter. Although soil properties and soil water may interact strongly with P availability to plants, the entire P-cycle resembles the N-cycle, as described by Power (1972), and a similar hypothesis could be developed for P.

One major difficulty in testing such hypotheses is that few previous range fertilization studies have been conducted long enough to quantify the flow rates and balance the N, or P, cycling within the soil-plant ecosystem. Quantifying these processes is inherent in determining the resulting quantity and quality of the grassland forages produced. The importance of forage quality in beef production on rangeland was emphasized by Rogler and Lorenz (1957, 1969). Improved levels of N and P in rangeland forages have been maintained by single high-rate or annual low-rate applications of N and P fertilizer for 4 to 6 years (Thomas 1961; Read 1965; Smoliak 1965; Black 1968; and Power and Alessi 1971).

The objectives of this paper are to consider the 8-year annual variations in plant N and P content and uptake as influenced by N and P fertilization and available water supplies, and to evaluate nutrient cycling of N and P over time in relation to the published hypotheses of Power (1972) and Cole et al. (1977).

Materials and Methods

Details of the study site, experimental design, fertilizer treatments, and harvesting methods are given in previous papers (Wight and Black 1972, 1979). At the beginning of the study, soil properties were reported (Black and Wight 1972), which included soil texture, pH, organic matter, total soil N and NO_3-N, and $NaHCO_3$ soluble P. This experiment design was a randomized block, split-plot with P treatments of 0, 112, and 224 kg P/ha as main plots and N treatments of 0, 112, 336, and 1,008 kg N/ha as subplots. Fertilizer treatments were applied in a single application in 1969.

The species composition of the plant community in 1969 was described in detail by Wight and Black (1972) and it was again described after 8 years (Wight and Black 1979). Unless otherwise specified, we grouped plant species into two major 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, fringed sagebrush (*Artemisia frigida*) and other shrubs]. Plant N was determined by the Kjeldahl method modified to exclude plant nitrates (Jackson 1958), and percent crude protein was calculated (% N × 6.25). Plant P was determined colorimetrically following wet oxidation of plant tissues (Jackson 1958). All significant differences in above-ground plant N and P concentrations and uptake discussed significant at the 5% confidence level unless otherwise indicated.

In 1973, 5 years after we applied the initial N and P fertilizer treatments, we took 20-cm diameter soil cores to a 30-cm depth, sliced the core horizontally into selected increments, and by soaking and washing procedures, separated plant root material from the soil. Goetz (1969) and Power and Alessi (1971) working on similar soils found that 80% or more of the root material under native range was contained in the top 30 cm of soil profile. Three soil cores were taken within both the unfertilized and the fertilized (334 kg N/ha plus 224 kg P/ha) plots, and total dry weight of root material, N and P content of roots, and total N and P uptake in the roots were determined. Soil samples were also taken periodically by 30-cm increments to a 3-m depth and soil NO_3-N was determined by the phenoldislphonic acid method (Jackson 1958).

Results and Discussion

Shrubs and forbs consistently had a higher plant N and P content regardless of fertilization than western wheatgrass or blue grama (data not shown). The unfertilized sedges, needleandthread, and particularly junegrass, had the lowest N and P content, but with N and P fertilization they were about equal to

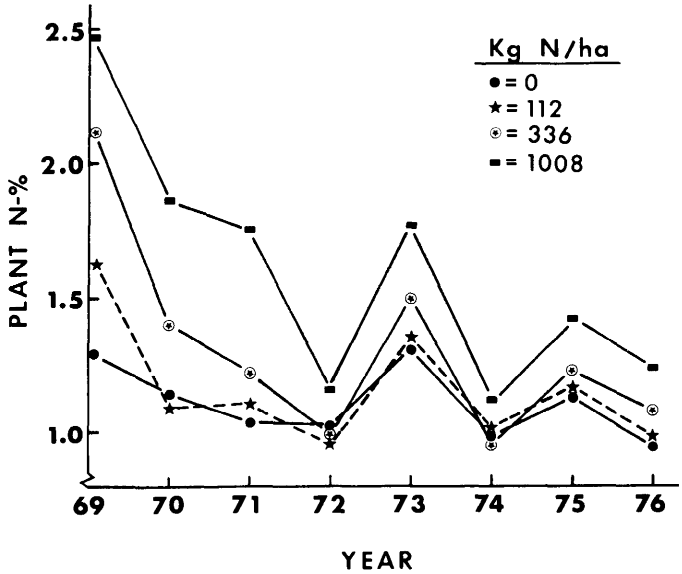

Fig. 1. *Average plant N content of grasses as influenced by N fertilization and years.*

western wheatgrass and blue grama.

Plant N and P content and uptake of the above-ground portion by the grasses and nongrasses (Figs. 1, 2, 3, and 4) were abnormally high in the fertilized plots the first year of the study (1969) for three reasons: First, growing season precipitation (April 1 to July 15) was the highest of all study years; second, the soil profile was moist throughout the root zone to a 2-m depth at the beginning of the growing season; and third, the relatively high rates of N and P applied were readily available to plants under these moisture conditions because only limited quantities of applied N and P had time to be immobilized into the soil-root-organic matter sink-system. Some of these factors were still operative the second year for the two highest rates of N and P applied. However, in 1970, all N and P rates reached a

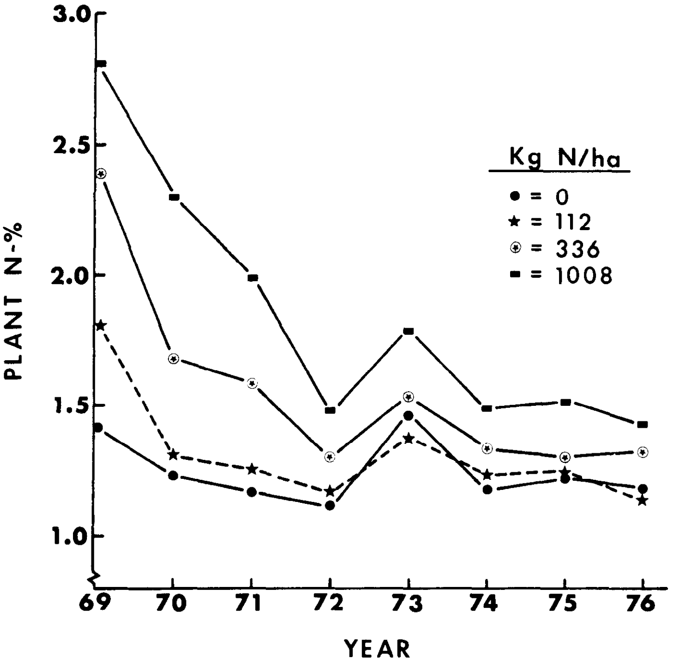

Fig. 2. *Average plant N content of nongrasses as influenced by N fertilization and years.*

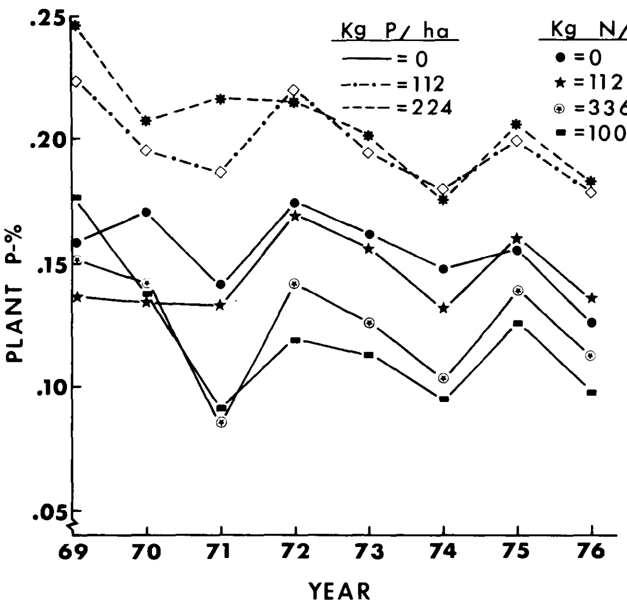

Fig. 3. *Average plant P content of grasses as influenced by N fertilizer applied alone, P fertilization, and years.*

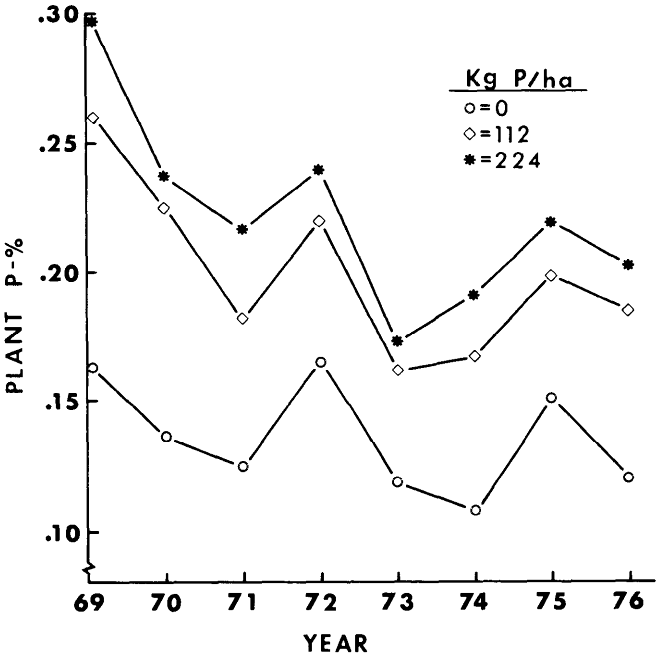

Fig. 4. *Average plant P content of nongrasses as influenced by P fertilization and years.*

relatively stable rate of availability in relation to the unfertilized grassland system, as shown by the N- and P-uptake data presented in Figures 5 and 6.

Plant N and P content

Since our data showed that plant N content of grasses and nongrasses was not significantly influenced by P fertilization, we averaged N content data for each N rate over all P-fertilizer treatments (Figs. 1 and 2). Variations in N content of both grasses and nongrasses were influenced (in order of importance) by rate of N applied, years (climate), and the year by N-rate interaction.

After the first 2 years, variations in N content of grasses and nongrasses within each N treatment were related primarily to available water supplies and to the quantity of forage produced. For example, in 1972, a "wet" year, forage production was high and plant N content decreased because the lush plant growth diluted plant N contents (Figs. 1 and 2). Conversely, in a "dry" year, such as 1973, production was low and N content increased within each level of N applied. This illustrates what many livestock producers have known for a long time, that beef production can be lower in "wet" than in drier years.

Plant P content of grasses significantly decreased as N rates increased without P fertilization, but when 112 or 224 kg P/ha was applied, N rates had no significant influence on plant P content. For this reason, we presented (Fig. 3) plant P content of grasses as an average of all N rates of the 112 and 224 kg P/ha treatments, whereas for the 0 kg P/ha treatment, N rates are presented individually (Fig. 3).

Without P fertilization, the 112, 336, and 1,008 kg/ha rates of N depressed plant P content significantly for 2,7, and more than 8 years, respectively. The negative effect of applying N-fertilizer alone on plant P content obtained in this study agreed with previous research (Smika et al. 1960; Cosper et al. 1967; Black 1968). Adding either 112 or 224 kg P/ha increased the P content in the above-ground plants to an adequate level for livestock feed in a maintenance ration (National Research Council 1976). Without P-fertilization, N applied alone decreased plant P content far below adequate levels for livestock.

Plant P content of the nongrasses was controlled primarily by rate of P applied, and secondly years, with no significant interaction between N- and P-fertilizer treatments. Therefore, N rates were combined within each P rate and the mean plant P content as influenced by P rates and years are shown in Figure 4. Plant P content of the grasses and nongrasses varied considerably among years. However, the availability of native and added P was controlled principally by available water supplies after the first 2 years. For example, in "wet" years, like 1972 and 1975, plant P content of the grasses and nongrasses was relatively high within each fertilizer treament (Figs. 3 and 4). Conversely, in "dry" years such as 1971 and 1974, plant P content was low. These trends were most conspciuous when no P fertilizer was applied. However, the actual P levels maintained in both grasses and nongrasses with P fertilization, regardless of year effects, was 30 to 50% greater than when no P was applied.

Plant N- and P-uptake

Plant N uptake for the unfertilized native grassland system over the 8-year period was 97 kg/ha, averaging 12 kg N/ha/yr. Without P added, plant N uptake was 58, 125, and 198 kg N/ha greater than the check for the 112, 336, and 1,008 kg/ha N rates, respectively. With P added, plant N uptake was 54, 169, and 273 kg N/ha greater than the check for the 112, 336, and 1,008 kg/ha N rates, respectively. Phosphorus fertilization improved plant N uptake for 2, 4 and at least 8 years for the 112, 336 and 1,008 kg/ha rates of N, respectively, as compared with the same N levels without P fertilization.

However, the same amount of N uptake has occurred, or will probably occur, with and without P fertilization for the 112 and 336 kg N/ha rates (Fig. 5). Extrapolation of the curves in Figure 5 shows that plant N uptake should reach the same amount, with or without P added, in 6 years for the 112 kg N/ha rate and in 13 years for the 336 kg N/ha rate. Regardless of P fertilization, one could anticipate that the 112, 336, and 1,008 kg N/ha rates should still be increasing average N uptake 0.5, 2.6, and 10.1 kg

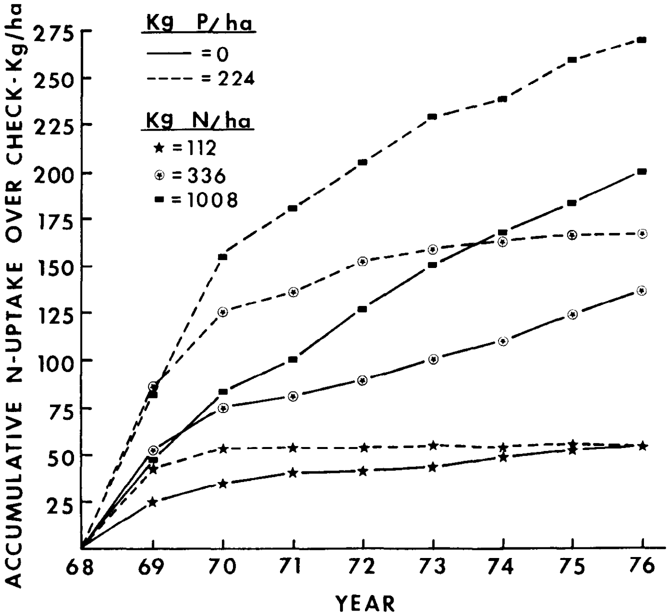

Fig. 5. *Accumulative plant N uptake above the unfertilized check as influenced by various N rates, with or without P, during the 8-year period.*

N/ha/yr, respectively for a period of 6, 13, and more than 13 years.

The actual amount of N fertilizer recovered in the harvested above-ground portion for the 112, 336, and 1,008 kg/ha rates of N after 8 years was 51.4, 37.1, and 19.6% without P, respectively, and 48.6, 50.5, and 27.1% with P added, respectively. Several more years of data would be needed before the maximum recovery of N-fertilizer could be obtained for the two highest rates of N applied.

For a given rate of N applied, accumulative P uptake by plants for the 112 and 224 kg/ha rates of P were not significantly different. Therefore, only plant P-uptake data for the 0 and 224 kg/ha P rates are shown in Figure 6. Cumulative P uptake by range plants in the unfertilized system was 12.6 kg P/ha over the 8-year period, averaging 1.6 kg P/ha/yr. The increase in plant P uptake, resulting from adding 224 kg/ha of P alone, was only 2.6 kg P/ha over the 8-year period, averaging 0.3 kg P/ha/yr. However, when 112, 336, and 1,008 kg N/ha were applied in combination with 224 kg P/ha, plant P uptake increased an additional 12.3, 24.1, and 32.6 kg P/ha above the check in 8 years, averaging 1.5, 3.0, and 4.1 kg P/ha/yr, respectively. With P fertilization, plant P uptake increased 98, 191, and 258% above the check with 112, 336, and 1,008 kg N/ha applied, respectively. Plant recovery of P fertilizer in the above-ground forage harvested for the high N rate was 27 and 15% for the 112 and 224 kg/ha rates of P, respectively, after 8 years.

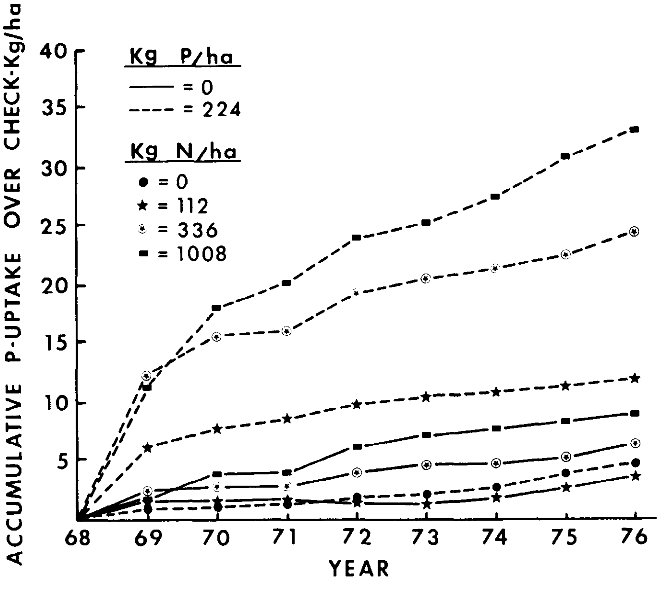

Fig. 6. *Accumulative plant uptake above the unfertilized check as influenced by various N rates, with or without P, during the 8-year period.*

After the first 2 years, the increase in plant P uptake resulting from N and P fertilization continued to increase at a rather stable rate in relation to the unfertilized native grassland system. Since 1971, plant P uptake from the 0, 112, 336, and 1,008 kg/ha N rates with 224 kg/ha of P applied increased 0.3, 0.9, 1.2, and 2.5 kg P/ha/yr, respectively, above the check. If we assume that the difference due to N and P fertilization continued at the same levels as they did during the last 6 years of the study, then the 224 kg/ha rate of P should increase plant P uptake for 738, 235, 167, and 76 years for the 0, 112, 336, and 1,008 kg/ha rates of N, respectively, if the above-ground herbage was harvested and removed from the land each year. In an actual grazing system, where appreciably smaller amounts of P would be removed, P-fertilizer effects would undoubtedly last almost indefinitely.

Root-Plant-Soil N and P Relationships

Soil cores were taken within the fertilized (336 kg N/ha plus 224 kg P/ha) and unfertilized plots and total root material, N and P content of roots, and N and P uptake by roots, was determined by selected soil depth increments (Table 1). Fertilized plots had 24,310 kg/ha of root material in the upper 30.5 cm of soil as compared to 20,700 kg/ha for the check. These amounts of root material resembled that reported by Goetz (1969) but are a little less than those reported by Power and Alessi (1971). The fertilized grassland system not only had 3,610 kg/ha more root material, but the N and P contents of the roots were much higher than those from the unfertilized system. Root material obtained from fertilized plots contained 116 kg/ha more N and 7.7 kg/ha more P than did root material obtained from unfertilized plots. These data illustrate the potential of the grassland ecosystem to immobilize relatively large quantities of N and P fertilizer in the

Table 1. Distribution of herbage root material, N and P content of roots, and N and P uptake by roots as influenced by N-P fertilization 5 years after initial application.

Soil depth (cm)	Total root material (kg/ha)	Root N content (%)	Total N in roots (kg/ha)	Root P content (%)	Total P in roots (kg/ha)
		Unfertilized			
0– 3.0	11,250	1.03	116	.079	8.9
3.0– 9.0	5,110	.75	38	.076	3.9
9.0–15.2	1,810	.64	12	.070	1.3
15.2–23.9	1,430	.60	9	.057	.8
23.9–30.5	1,100	.55	6	.054	.6
Total	20,700		181		15.5
		Fertilized (336 kg N/ha plus 224 kg P/ha)			
0– 3.0	14,180	1.45	206	.099	14.0
3.0– 9.0	5,400	.97	52	.101	5.5
9.0–15.2	1,870	.83	16	.087	1.6
15.2–23.9	1,650	.87	14	.070	1.2
23.9–30.5	1,210	.77	9	.073	.9
Total	24,310		297		23.2

below-ground root system.

In 1973, soil NO_3-N determinations were made by 30-cm increments to a 3-m depth in the unfertilized check and the fertilized (336 kg N/ha plus 224 kg P/ha) plots. The check contained 9 kg/ha, of soil NO_3-N while fertilized plots still contained 47 kg/ha, 5 years after application. Therefore, fertilized plots contained 38 kg/ha more soil NO_3-N and 116 kg/ha more N in the roots than did unfertilized plots. By 1973, we could account for 163 kg/ha more N than from the check in the aboveground herbage harvested from fertilized plots. We applied 336 kg/ha of N and by 1973 we could account for 38, 116, and 163 kg/ha of applied N in the soil, roots, and above-ground herbage, respectively, which totals 317 kg N/ha or 94% accountability of the initial 1969 application.

Since relatively high amounts of N are tied-up in the below-ground root system of fertilized plant communities, it is understandable that the release of this N through natural decomposition processes to the available N pool for later uptake by above-ground herbage would be a very slow process. Therefore, the projected time length that plant N and P uptake would be influenced by high N and P rates (as discussed earlier) may be very realistic for the cool-semiarid climate of the northern Great Plains.

Since unfertilized systems contain relatively large quantities of root material with low N and P content, the root system itself has a high potential to immobilize relatively large quantities of any inorganic N or P fertilizer material applied. This immobilized portion of the N and P fertilizer applied will not become available for cycling to the above-ground herbage until the inorganic soil pool of available N is nearly exhausted. Even though yield responses to 112 and 336 kg/ha N rates ceased sometime during the 8-year period, plant N uptake was still 0.5 and 2.6 kg N/ha greater, respectively, in fertilized than in unfertilized check plots after 8 years. The source of this N is undoubtedly from mineralization of organic matter, principally plant root material.

Conclusions

From the range management aspects of production and quality, it would be desirable to know the relative predominance and sensitivity to fertilization of grasses, sedges, forbs, and shrubs within the plant community under question. We found that for the grasses, N and P fertilization had a greater effect on production, N and P content, and N and P uptake than did years (climate). Conversely, the production and N and P uptake of nongrasses were controlled more by years than by fertilization and only the N and P content of nongrasses could be controlled by respective additions of N and P fertilizer. Therefore, the quality (N and P content) of both grasses and nongrasses was more sensitive to N and P fertilization than to climatic-year effects. This indicated that rather specific fertilizer management practices could be developed which would exert some control over species composition, production, and quality of grassland ecosystems.

The unfertilized plant system produced 605 kg/ha of protein over the 8-year period, while native range receiving 112, 336, and 1,008 kg/ha of N along with P fertilization produced 945, 1,660, and 2,310 kg/ha of crude protein over the same period. More important, these same N rates still produced an average of 3.1, 16.3, and 63.1 kg/ha/yr more crude protein at the end of the 8-year period than did the unfertilized check, even though little, or no measurable increases in production were obtained from the 112 or 336 kg/ha N rates the last year. Many researchers have assumed that when the production of a fertilized grassland system had decreased to the same level as the check, there would be no further benefits to be obtained from fertilization. The results of this study showed that the benefits of N and P fertilization on important herbage quality factors persisted after yield responses had ceased. Such quality factors as plant P content become even more important in relation to livestock production in P-deficient rangeland in the glacial till soil regions of the northern Great Plains (Black 1968; Black and Wight 1972).

In this study, we applied relaively high rates of N and P fertilizer principally to identify the possible production potential of a typical range site in the northern Great Plains climate if soil N and P were not limiting in the soil-plant system. We recognize that maximizing forage production is not the most economical or desirable target. Nevertheless, the results of this study indicated the hazards of making economic and management decisions solely on production without considering the long-term benefits of N and P fertilization on both production and forage quality—benefits that may persist for several years after yield responses are no longer apparent.

Literature Cited

Black, A.L. 1968. Nitrogen and phosphorus fertilization for production of crested wheatgrass and native grass in northeastern Montana. Agron. J. 60:213-216.

Black, A.L., and J. Ross Wight. 1972. Nitrogen and phosphorus availability in fertilized rangeland ecosystem of the Northern Great Plains. J. Range Manage. 25:456-460.

Cole, C. Vernon, George S. Innis, and J.W.B. Stewart. 1977. Simulation of phosphorus cycling in a semiarid grasslands. Ecology 58:1-15.

Cosper, H.R., J.R. Thomas, and A.Y. Alsayegh. 1967. Fertilization and its effect on range improvement in the Northern Great Plains. J. Range Manage. 20:216-222.

Goetz, Harold. 1969. Root development and distribution in relation to soil physical conditions on four different native grassland sites fertilized with nitrogen at three different rates. Can. J. Plant Sci. 49:753-760.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice-Hall, Inc., Englewood Cliffs, N.J. p. 149-175, 183-191, 197-201.

National Research Council. 1976. Nutrient Requirements of Beef Cattle. Fifth revised edition, Nat. Acad. of Sci., Washington, D.C. 56 p.

Power, J.F., and J. Alessi. 1971. Nitrogen fertilization of semiarid grasslands: Plant growth and soil mineral N levels. Agron. J. 63:277-280.

Power, J.F. 1972. Fate of fertilizer nitrogen applied to a northern Great Plains rangeland ecosystem. J. Range Manage. 25:367-371.

Read, D.W.L. 1969. Residual effects from fertilizer on native range in southwestern Saskatchewan. Can. J. Soil Sci. 49:225-230.

Rogler, George A., and Russell J. Lorenz. 1957. Nitrogen fertilization of Northern Great Plains rangelands. J. Range Manage. 10:156-160.

Rogler, George A., and Russell J. Lorenz. 1969. Pasture productivity of crested wheatgrass as influenced by nitrogen fertilization and alfalfa. U.S. Dep. Agr. Tech. Bull. 1402.

Rogler, George A., and Russell J. Lorenz. 1974. Fertilization of mid-continent range plants, p. 231-254. *In:* D.A. Mays (Ed.). Forage Fertilization, Amer. Soc. Agron; Crops Sci. Soc. Amer., and Soil Sci. Soc. Amer.

Smika, D.E., H.J. Haas, and G.A. Rogler. 1960. Yield, quality and fertilizer recovery of crested wheatgrass, bromegrass, and Russian wildrye as influenced by fertilization. J. Range Manage. 13:243-246.

Smoliak, S. 1965. Effects of manure, straw, and inorganic fertilizers on Northern Great Plains ranges. J. Range Manage. 18:11-15.

Thomas, J.R. 1961. Fertilizing bromegrass-crested wheatgrass in western South Dakota. S. Dak. Agr. Exp. Sta. Bull. 504.

Wight, J. Ross, and A.L. Black. 1972. Nitrogen and phosphorus availability in a fertilized rangeland ecosystem of the northern Great Plains. J. Range Manage. 25:456-460.

Wight, J. Ross. 1976. Range fertilization in the Northern Great Plains. J. Range Manage. 29:180-185.

Wight, J. Ross, and A.L. Black. 1978. Soil water use and recharge in a fertilized mixed prairie plant community. J. Range Manage. 31:280-282.

Wight, J. Ross and A.L. Black. 1979. Range Fertilization: Plant responses and water use. J. Range Manage. 32:345-349.