Response of established forages on reclaimed mined land to fertilizer N and P

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Abstract

A field study was conducted from 1981 through 1986 on an established stand of grass and legume species on topsoiled coal-mine spoils in northwest Colorado to evaluate the effects of N and P fertilization on dry matter production, species composition, canopy cover, and forage crude protein and P concentrations. Fertilizer treatments included annual fall applications in 1981 through 1985 of: 0, 28, 56, 112, and 224 kg N ha^{-1}; 56 kg P ha^{-1}; and 112 kg N ha^{-1} + 56 kg P ha^{-1}. Additionally, single fall applications of N were applied in 1981 through 1983 at rates of 0, 28, 56, 112, 224, and 448 kg N ha^{-1} to other plots that had not been previously fertilized. Plots were harvested at grass anthesis in 1982 through 1986. Fertilizer P significantly increased forage P concentration but did not significantly affect yield, crude protein concentration, or species composition. Fertilizer N did not significantly affect species composition or forage P concentration but did significantly increase dry matter production and crude protein concentration with increased N rate. Averaged over the 5 years of the study, annual application of 28, 56, 112, and 224 kg N ha^{-1} increased herbage production by 23, 19, 19, and 11 kg per kg N applied, respectively. On those plots receiving a single application of fertilizer N, significant increases in dry matter production with increased N rate were noted only during the first growing season after N fertilization. Significant yield response to carry-over fertilizer N was noted in the second (and occasionally third) growing seasons only at the 448 kg N ha^{-1} rate. The data indicate that annual applications of fertilizer N would be more effective than infrequent applications of high rates of N on these reclaimed mined lands.

Key Words: fertilization, botanical composition, forage yield

The deficiency of plant-available nitrogen (N) is a common limitation to successful revegetation and long-term stability of lands disturbed by surface mining (Reeder and Sabey 1987). Nitrogen deficiency seldom limits seedling establishment on reclaimed mined land (Cook et al. 1974, Woodmansee et al. 1978, McGinnies and Crofts 1986). However, N deficiency can affect the long-term stability of a site since some plant communities fail to persist on N-deficient sites, despite initial seedling establishment and fertilization (Reeder and Sabey 1987). Depending on its depth and quality, replaced topsoil can ameliorate N deficiencies by providing mineralizable organic N. Both herbage and root production have been found to increase with increasing depth of topsoil (McGinnies and Nicholas 1980, Redente and Hargis 1985). However, topsoil of sufficient depth and quality to alleviate N deficiencies is not always available, and supplemental fertilizer N may be needed a number of years after stand establishment.

Numerous studies have reported that availability of N limits grassland production (McGinnies 1968; Power and Alessi 1970, 1971, Wight 1976, Wight and Black 1979, and Power 1980a), and other studies report that availability of water primarily regulates response to N fertilzer (Colville et al. 1963, Smika et al. 1965, Johnston et al. 1969, Power 1980b). The question arises as to whether N applied in 1 large application could be stored for long periods in the soil and be available for plant use in times of adequate water. Single applications would be advantageous in terms of reduced handling and labor costs. Studies by Power and Alessi (1971) and Power (1967) suggest that single applications of high rates of N fertilizer to nondisturbed semiarid grasslands could develop a pool of available N that plants could use whenever water is not limiting. However, the effectiveness of single applications of high rates of N fertilizer has not been adequately tested for mined lands.

Studies have been conducted to evaluate the effects of fertilizer on establishment and development of seeded plants on disturbed lands (DePuit and Coenenberg 1979; Doerr et al. 1983; Redente et al. 1984). However, little is known about the effects of N fertilizer rate and frequency on reclaimed mined lands that have an established stand (>5 years) of vegetation. Moreover, limited information is available concerning optimum fertilizer rates or residual effects on reclaimed mined lands in the central Rocky Mountain region. This study was conducted to evaluate the effects of rate and frequency of N and P fertilizer on dry matter production, forage quality, canopy cover, and species composition of an established stand of grass and legume species on topsoiled coal mine spoils.

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Methods

The study was conducted at Energy Mine No. 3 of the Colorado Yampa Coal Company located 32 km southwest of Steamboat Springs, Colorado. Elevation was 2,100 m and average annual precipitation was 430 mm. Coal had been strip-mined from the area prior to 1976. Spoils were a mixture of shales and sandstones from the Williams Fork Formation of the Upper Cretaceous Mesa Verde group. In October, 1976, the study area was topsoiled to a depth of 20 to 30 cm with a heterogeneous mixture of the A and B horizons of a Routt loam (fine montmorillonitic Typic Argiboroll).

Following placement of the topsoil, the area was seeded in October, 1976, with a mixture of plant species consisting of: 5.62 kg ha^{-1} smooth brome *(Bromus inermis* L.), 6.74 kg ha^{-1} intermediate wheatgrass (*Elytrigia intermedia* (Host) Nevski), 3.37 kg ha^{-1} western wheatgrass (*Pascopyrum smithii* (Rydb.) Love), 2.25 kg ha^{-1} crested wheatgrass (*Agropyron desertorum* (Fisch. ex Link) Schult.), 1.12 kg ha^{-1} hard fescue *(Festuca ovina duriuscula* L.), 1.12 kg ha^{-1} Kentucky bluegrass *(Poa pratensis* L.), and 0.56 kg ha^{-1} alfalfa *(Medicago sativa* L.). The initial stand of vegetation was good and grazing was prohibited. At the beginning of this study in 1981, species composition (as estimated from visual determinations of canopy cover) was approximately 50% smooth brome, 40% intermediate wheatgrass, and 10% all other.

Fertilized plots, 5 × 5 m, were established in September 1981. Plots were arranged in a randomized complete block design with 3 replications. Vegetation was mowed with a rotary mower to a 5.0–7.5 cm height and the various fertilizer treatments were broadcast onto the soil surface. The fertilizer treatments included annual fall (early October) applications in 1981 through 1985 at the following rates: 0, 28, 56, 112, and 224 kg N ha^{-1}; 56 kg P ha^{-1}; and 112 kg N ha^{-1} + 56 kg P ha^{-1}. Nitrogen was applied as ammonium nitrate and

P as treble superphosphate. Additionally, single application treatments at rates of 0, 28, 56, 112, 224, and 448 kg N ha^{-1} were broadcast in October 1981, 1982, and 1983 onto other plots that had not been previously fertilized.

Stands were evaluated in mid-July from 1982 through 1986 when the grasses were at anthesis. Canopy cover was visually determined, always by the same person, within five, 0.21-m^2 areas selected randomly within each plot, and species composition was estimated from the cover data (Cook and Bonham 1977). A forage sample from a 8.5 m^2 area of each plot was harvested with a rotary mower to a 5.0 – 7.5 cm height and weighed to determine yield. Subsamples of the mowed vegetation were oven-dried at 60° C to determine dry matter production. After vegetation was sampled, all remaining vegetation within the plots was mowed to a 5.0–7.5 cm height and removed from the plots so that plant samples taken in subsequent years represented the current year's production. Nitrogen and P concentrations were determined colorimetrically on plant samples ground to 40 mesh and digested using a modified Kjeldahl-peroxide digestion procedure.

Data were evaluated by analyses of variance and regression analysis. Tukey's Q Test was used where appropriate to evaluate significant differences among treatment means. All differences mentioned in this paper are significant at the $P<0.05$ level.

Results and Discussion

Physical and chemical properties of the topsoil and spoil are given in Table 1. The data indicate that plant growth at the research site is limited by nutrient deficiencies but not by toxicities. Neither material is saline nor sodic. The level of bicarbonate P in the topsoil indicates an adequate level of plant-available P, while the level in the spoil is considered deficient for plant growth (Olsen and Sommers 1982). Both topsoil and spoil contain relatively low levels of organic N and organic C. The organic matter concentration of the spoil material is comparable to that of the topsoil, but the spoil organic matter is considerably less susceptible to microbial decomposition and its potential for supplying plant-available N is very low (Reeder 1988). Although texturally classified as a clay loam (Table 1), the water holding capacity and the cation exchange capacity of the spoil material are low and more closely resemble those of a sandy loam (Donahue et al. 1983).

Table 1. Average physical and chemical characteristics of the topsoil and spoil materials sampled from the nonfertilized control plots at the end of this study.

	Topsoil	Spoil
Textural Class	Clay	Clay loam
pH	7.3	7.9
Electrical Conductivity (EC) (dS/m)	0.3	2.2
Sodium Adsorption Ratio (SAR)	0.3	0.3
Water Content at 0.033 MPa (%, g/g)	20.6	15.4
Cation Exchange Capacity (cmol/kg)	34.8	11.0
Kjeldahl-N (mg/kg)	1290	1150
NH_4-N (mg/kg)	1.3	6.1
NO_3-N (mg/kg)	3.1	4.8
Total C (g/kg)	19.8	21.3
CO_3-C (g/kg)	1.1	5.5
Total P (mg/kg)	597	937
Bicarbonate P (mg/kg)	13.5	1.8

Forage Yield

Dry matter production on plots receiving no fertilizer averaged 1,040 kg ha^{-1} over 1982 through 1986, and ranged from 720 kg ha^{-1} in 1982 to 1,304 kg ha^{-1} in 1984. For release of bond under current regulations, mining companies must show that dry matter production and aerial cover on reclaimed mined lands are comparable

Table 2. Dry matter production (Y) as related to nitrogen fertilization rate (X) on those plots receiving annual applications of 0 - 224 kg ha^{-1} fertilizer N.

Year	Quadratic regression equations	R^2
1982	$Y = 643 + 14.55 X - 0.039 X^2$	0.82
1983	$Y = 1123 + 26.02 X - 0.054 X^2$	0.84
1984	$Y = 1147 + 42.35 X - 0.135 X^2$	0.82
1985	$Y = 688 + 27.80 X - 0.076 X^2$	0.85
1986	$Y = 957 + 23.37 X - 0.070 X^2$	0.82

to those on a non-mined reference area. A comparison made in 1982 revealed that dry matter production on the non-fertilized study plots was significantly lower than dry matter production on the non-mined reference area. The non-mined reference area averaged 1,350 kg ha^{-1} in 1982 and consisted of 31% grasses, 17% forbs, and 52% shrubs (primarily big sagebrush) (Colorado Yampa Coal Company data, 1987 personal communication). In comparison, dry material production on the non-fertilized research plots averaged 720 kg ha^{-1} and consisted of >99% grasses and <1% forbs and alfalfa.

The application of P did not significantly affect dry matter production in any of the 5 years of this study. Other studies have reported similar results (Lutwick and Smith 1977, Rauzi 1979, Read and Winkleman 1982, Halvorson and Bauer 1984, Redente and Hargis 1985). Wight and Black (1979) reported that P fertilization did not significantly increase yields on a mixed prairie range in eastern Montana except when N was nonlimiting. They found no yield response to P when applied with 112 kg N ha^{-1}, but a significant yield response when applied with 336 or 1,008 kg N ha^{-1}. In our study, the failure of P to increase production in those plots annually receiving 112 kg N ha^{-1} plus 56 kg P ha^{-1}, as compared to

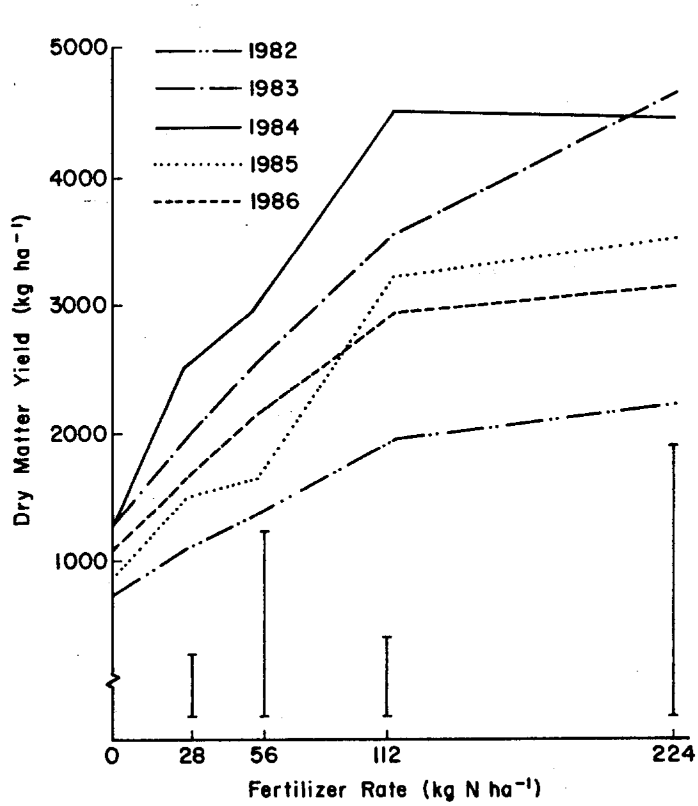

Fig. 1. *Annual dry matter production as affected by annual applications of 0, 28, 56, 112, and 224 kg N ha^{-1} fertilizer. Error bars for each N rate indicate the least significant difference (according to Tukey's Q test) in dry matter production among years.*

those plots annually receiving only 112 kg N ha^{-1}, suggests that at 112 kg N ha^{-1}, N was still the growth-limiting factor.

On those plots receiving annual applications of N, the increase in dry matter production with increase in annual N rate was best described with quadratic regression equations for each of the 5 years of this study (Table 2). These equations demonstrate that as the rate of applied N increased, the dry matter production per unit of applied N decreased. Averaged over the 5 years of the study, annual application of 28, 56, 112, and 224 kg N ha^{-1} increased herbage production by 23, 19, 19, and 11 kg per kg N applied, respectively. Dry matter production varied significantly from year to year, ranging from 1,102–2,532 kg ha^{-1} on plots receiving 28 kg N ha^{-1}, to 2,250–4,650 kg ha^{-1} on plots receiving 224 kg N ha^{-1} annually (Fig. 1). Annual variations in both precipitation and temperature may be largely responsible for the annual variations in yield response to fertilizer N found during the 5 years of this study (McGinnies 1968, Power 1986). Leaching losses of fertilizer N below the rooting zone may also have affected yield responses to N application. Leaching losses of fertilizer ^{15}N have been measured in studies conducted on these topsoiled spoil materials (Reeder, unpublished data), and are thought to be due in part to the lower water holding capacity of the spoil material (Table 1).

Single applications of fertilizer N ranging from 28 to 448 kg ha^{-1} (applied in the autumns of 1981, 1982, and 1983 to plots not previously fertilized) increased yield with increasing N rates during the first growing season after N fertilization (i.e., 1982, 1983, and 1984). On those plots fertilized in October 1981, significant dry matter increases with increased N rate were noted in 1982 (Fig. 2). However, in 1983 and 1984, increased dry matter production due to carry-over of N fertilizer was noted only at the 448 kg N ha^{-1} rate, and no significant response was noted in 1985 or 1986. Similar trends were found in dry matter production on those plots that received single applications of fertilizer N in the falls of 1983 and 1984 (data not shown). On those plots, however, response to fertilizer N applied at 448 kg ha^{-1} carried over only to the second growing season after application.

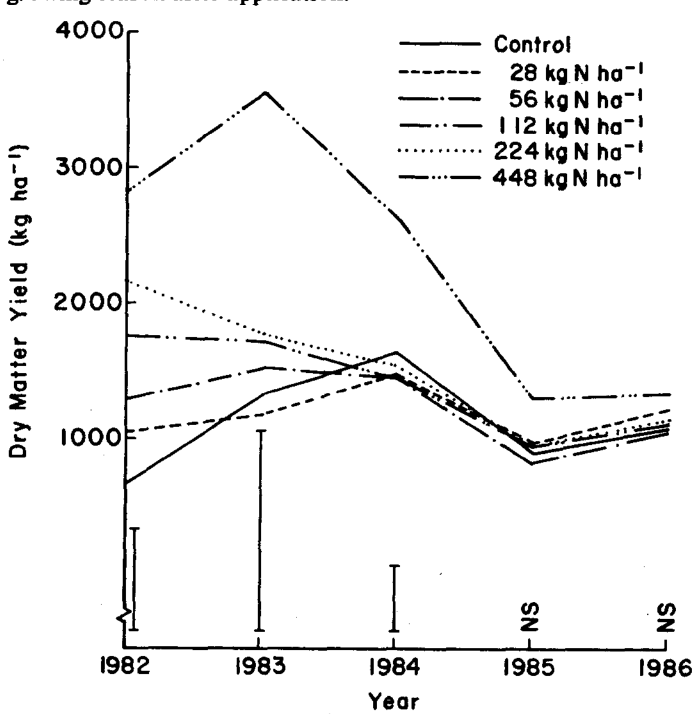

Fig. 2. *Dry matter production during a 5 year period as affected by a single application of 0, 28, 567, 112, 224 or 448 kg N ha^{-1} fertilizer in the fall of 1981. Error bars for 1982, 1983 and 1984 indicate the least significant difference (according to Tukey's Q test) in dry matter production among levels of N applied.*

Residual effects of single applications of fertilizer N on non-mined land forage production have been found to last from 1 to 10 years (McGinnies 1968; Power and Alessi 1971; Wight and Black 1979; Lutwick and Smith 1977, 1979; Rauzi 1979; Read and Winkleman 1982; and White 1985). These studies found that residual response is generally longer for higher N fertilizer rates, and that no significant carry-over is generally noted at lower rates. Forage yield response is generally greatest the first year after fertilization and gradually decreases with time (Wight and Black 1979). The fact that on our plots forage yield response to residual fertilizer N declined rapidly and not gradually may be due to 2 factors:

(1) The developing ecosystem on this mined-land is still accumulating biomass and nutrients as it progresses towards a new equilibrium between N demand and supply. Decades may be required for the root litter and the soil organic matter components to become fully developed and equilibrate, and until these components equilibrate, they act as sinks for N and deplete the amount of N available for annual plant growth (Woodmansee et al. 1978).

(2) The potential for nitrate leaching is greater in the mined lands studied here than in many nondisturbed grasslands. Nondisturbed grasslands frequently contain a well developed clayey B horizon with high water holding capacity (Woodmansee 1979). In contrast, the majority of the rooting zone in these mined lands is composed of unconsolidated spoil which has a fairly low water holding capacity (Table 1). Moreover, this disturbed-land ecosystem has probably not yet developed equilibrium levels of plant roots and microorganisms which are capable of extracting nitrate from solution before it leaches below the rooting zone (Woodmansee et al. 1981). Leaching losses of fertilizer ^{15}N have been measured in other studies conducted on these topsoiled spoil materials (Reeder, unpublished data).

Canopy Cover

Trends in canopy cover response to fertilizer N and P were similar to trends in yield response to fertilizer N and P. Canopy cover was highly correlated with dry matter production, with correlation coefficients *(r)* for any year generally greater than 0.95. Averaged over the 5 years of this study, aerial cover was 16, 27, 32, 54, and 67% on those plots annually receiving 0, 28, 56, 112, and 224 kg N ha^{-1}, respectively.

For bond release under current regulations, mining companies must show that dry matter production and aerial cover on reclaimed mined lands are comparable to those on a non-mined reference area. A comparison made in 1982 revealed that aerial cover on the non-fertilized plots was considerably lower (13%) than that on non-mined reference areas (80%). Shrubs (primarily big sagebrush) dominate the non-mined reference areas, contributing 52% of the cover, whereas grasses and forbs represent 31% and 17% of the cover, respectively. Only with the applications of 112 or 224 kg N ha^{-1} was cover on the research plots comparable to that of the non-mined reference areas.

Species Composition

Changes in species composition as the result of P fertilization have been reported for recently seeded mined lands (Halvorson and Bauer 1984). Moderate-to-high rates of fertilizer N have been found to change the composition of mixed species pastures (Power and Alessi 1971, Power 1980a, Halvorson and Bauer 1984). However, during the 5 years of the study reported here, neither N nor P fertilization significantly affected species composition. Vegetation growing on the plots was dominated by smooth brome and intermediate wheatgrass. These 2 species generally comprised over 90% of the species composition, with averages of 53.4% for smooth brome and 41.4% for intermediate wheatgrass. Crested wheatgrass, Kentucky bluegrass, and alfalfa accounted for most of the remaining species composition. Western wheatgrass and hard fescue were rarely found in the plots. The lack of a significant response of species composition to fertilizer N or P may be due to smilarities between the 2 dominant species in phenology, vigor, and growth response to fertilizer, that are sufficient to preclude differential stimulation.

Crude Protein Concentration of Vegetation

Crude protein concentration was used as a measure of forage quality. The average crude protein concentration of vegetation harvested from plots receiving no fertilizer was 6.6%, and ranged from 6.1% in 1986 to 8.8% in 1983. Annual application of fertilizer P did not significantly affect the crude protein concentration of harvested forage in any of the 5 years of this study, whereas the effect of annual N fertilization varied from year to year (Fig. 3). In 3 of the 5 years (1982, 1985, 1986), crude protein concentration significantly increased only at the 112 and 224 kg N ha^{-1} rates. In 1983 and 1984, there was no significant effect of fertilizer N on crude protein concentration. The crude protein values in 1983 for the control and for the 56 kg N ha^{-1} rate were highly variable among replicate plots and were thought to have resulted from harvesting a disproportionate amount of alfalfa during random sampling of some of the plots. The lack of response in 1984 to fertilizer N may have been due to dilution of crude protein concentration by high dry matter production (Fig. 1).

On plots receiving a single application of fertilizer N, the crude protein concentration of harvested forage was significantly affected by N rate during the first growing season after application. For those plots receiving N in the autumn of 1981, crude protein concentration varied significantly with N rate in 1982 and 1983, the first and second growing seasons after application (Fig. 4). However, by the third growing season, crude protein concentrations were no longer significantly affected by residual fertilizer N. Similar trends were found in the crude protein concentrations of vegetation in plots that received fertilizer N prior to the 1983 and 1984 growing seasons, except that the effect of fertilizer N on crude protein concentration did not carry over to the second growing season after fertilizer application (data not shown). In comparison, White (1985) found that single applications of low rates of fertilizer N affected crude protein concentration of western wheatgrass for 6 years after application.

Phosphorus Concentration of Vegetation

The annual application of fertilizer P significantly increased the P concentration of harvested vegetation. The P concentration of vegetation harvested from control plots averaged 0.160%, as compared to an average P concentration of 0.171% in vegetation harvested from P-fertilized plots. The P concentration of vegetation harvested from the P-fertilized plots did not change significantly from 1982 through 1986.

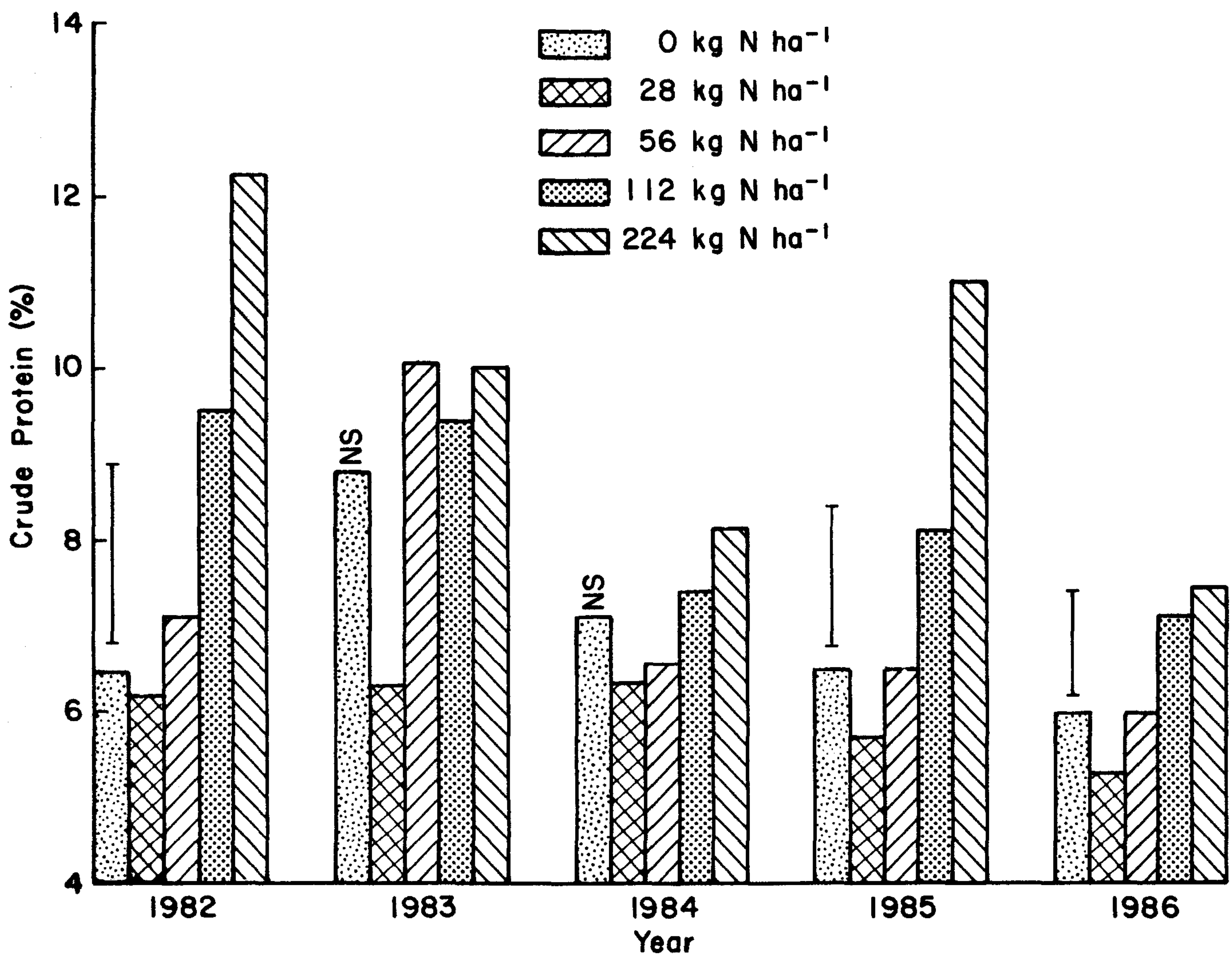

Fig. 3. *Annual crude protein concentration of forage as affected by annual applications of 0, 28, 56, 112, and 224 kg N ha^{-1} fertilizer. Error bars for 1982, 1985 and 1986 indicate the least significant difference (according to Tukey's Q test) in crude protein concentration among levels of N applied.*

For any given year, the P concentration of harvested vegetation was not significantly affected by either annual or single applications of fertilizer N. However, the average P concentration of vegetation harvested from control plots and from N-fertilized plots steadily and significantly declined from 0.178% in 1982 to 0.146% in 1986. The reduction of forage P concentration with N fertilization may be an indication that the increased plant growth obtained as a result of N fertilization caused a depletion of the available soil P as well as the fertilizer P initially applied (Read and Winkleman 1982). Other researchers have reported significant decreases in forage P concentration with N fertilization (Black 1968, Black and Wight 1979, Read and Winkleman 1982, White 1985). An explanation for the steady annual decline in forage P concentration from control plots is not apparent since the control plot soil plant-available P level at the end of this study averaged 12.5 mg/kg, a level which is considered adequate for plant growth (Olsen and Sommers 1982).

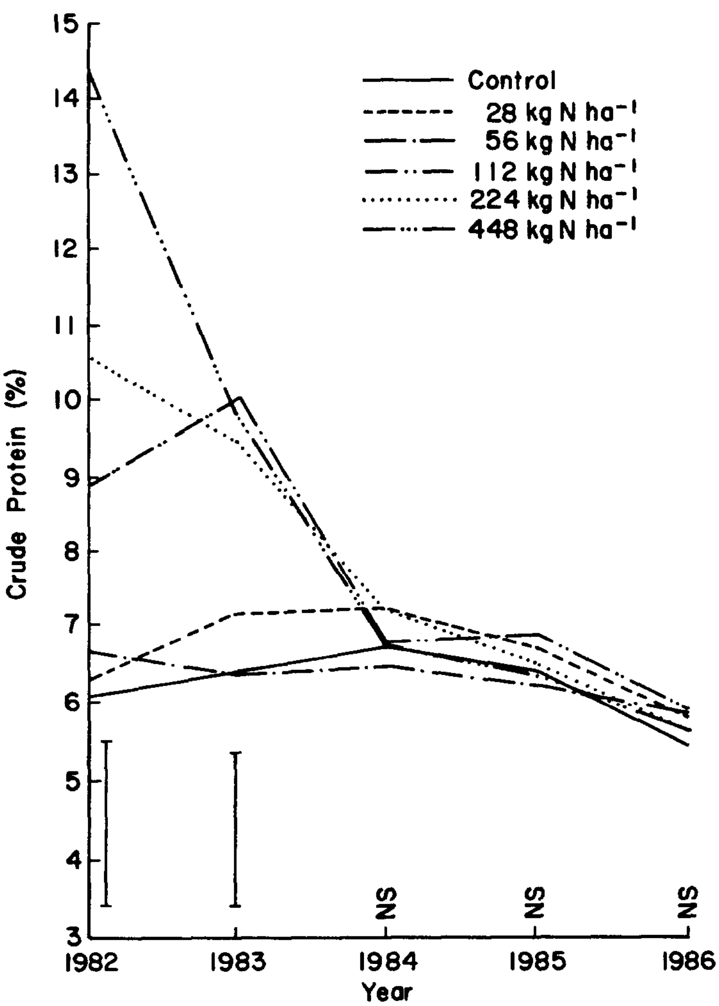

Fig. 4. *Crude protein concentration of forage during a five year period as affected by a single application of 0, 28, 56, 112, 224 or 448 kg N ha^{-1} fertilizer in the fall of 1981. Error bars for 1982 and 1983 indicate the least significant difference (according to Tukey's Q test) in crude protein concentration among levels of N applied.*

Conclusions

The data from this study suggest that although applications of high rates of N at infrequent intervals would reduce costs of fertilizer handling and distribution, such applications would not improve dry matter production after 2 or 3 growing seasons. Thus annual applications of fertilizer N on reclaimed mined land would be more effective than infrequent applications of high rates of N. However, under current regulations, annual fertilizer applications are not an acceptable way of meeting reclamation standards for disturbed mined lands. Yet on mined land that has been released from bonding and is to be grazed, the annual application of N at moderate rates may be justified for increased forage production and protein concentration. On the basis of the results from this study, each pound of N applied will provide at least 1 day's grazing for a yearling steer. The economic feasibility of applying N will depend on the cost of the N, the importance of obtaining additional forage, and the cost of getting the additional forage from other sources.

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