# Response of native species to variable nitrogen, phosphorus, and potassium fertilization on mine soils

by Philip John Hertzog

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University


Abstract:
Eastern Montana is a region in which coal mining in the past decade has resulted in the destruction of soil systems and vegetation. State law requires this land be reclaimed with the establishment of permanent, diverse, predominantly native plant communities. Fertilization is one management technique that may help to meet this legal requirement. This study evaluated the effects of several fertilization treatments on the establishment of vegetation on mine land.

A native species mixture was seeded on cover-soiled, regraded mine spoils in the fall of 1981 at Colstrip, Montana. The following spring, the site was fertilized with 24 treatments of N (0, 14, 28, and 56 kg N/ha), P (0, 112, and 168 kg P/ha), and K (0 and 28 kg K/ha) in factorial combination. Vegetational establishment was evaluated by measuring plant density, aerial biomass, canopy cover, and frequency by plant class and species. In addition, species diversity, evenness, and richness were calculated for each treatment.

After one growing season, P was the only fertilizer element to significantly affect vegetational establishment. Regardless of the level of N and K, P fertilization at 112 and 168 kg P/ha decreased density, aerial biomass, canopy cover, and frequency of warm season grasses. Legume aerial biomass and canopy cover were reduced by fertilization at 112 kg P/ha. The reduction of these two plant classes may be due to P fertilization increasing the competitive effect of other plant classes. Phosphorus fertilization increased the aerial biomass and canopy cover of annual forbs and annual grasses. Species diversity, evenness, and richness varied over the study site, but were not affected by fertilization.

It was recommended that P fertilization not be used the first growing season due to its negative effect on warm season grass and to an extent legume establishment. Nitrogen and K fertilization were not necessary for plant establishment under conditions of this study.

# RESPONSE OF NATIVE SPECIES TO VARIABLE NITROGEN, PHOSPHORUS, AND POTASSIUM FERTILIZATION ON MINE SOILS

by

Philip John Hertzog

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Land Rehabilitation

MONTANA STATE UNIVERSITY
Bozeman, Montana

March 1983

APPROVAL

of a thesis submitted by

Philip John Hertzog

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English useage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

February 10, 1983
Date

Chairperson, Graduate Committee

Approved for the Major Department

2/10/83
Date

Head, Major Department

Approved for the College of Graduate Studies

2-14-83
Date

Graduate Dean

## STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Philip J. Hertzog

Date Feb. 9, 1983

## ACKNOWLEDGEMENTS

Behind all graduate students there stands a host of individuals, whose invaluable support makes the successful completion of a research study possible. To name all these individuals is impossible, but there are those who deserve recognition.

Dr. Steve Young, my graduate committee chairman, deserves special recognition for his patience, technical advice, and encouragement. Dr. Frank Munshower and Dr. Paul Kresge provided advice on content and writing style. Bob Rennick and Patrick Platenberg supplied invaluable help in data collection, methodology, and plant identification. Dennis Neuman and Chris LeVine provided assistance on soil analyses. Ron Thorson's technical knowledge of computers and programming saved innumerable hours of statistical analyses. The typing skills of Jeanne Blee, as well as her knowledge of word processing were greatly appreciated. Finally, a special thanks goes to the Western Energy Company which provided financial support for this project.

TABLE OF CONTENTS

# LIST OF TABLES

LIST OF FIGURES

## ABSTRACT

Eastern Montana is a region in which coal mining in the past decade has resulted in the destruction of soil systems and vegetation. State law requires this land be reclaimed with the establishment of permanent, diverse, predominantly native plant communities. Fertilization is one management technique that may help to meet this legal requirement. This study evaluated the effects of several fertilization treatments on the establishment of vegetation on mine land.

A native species mixture was seeded on cover-soiled, regraded mine spoils in the fall of 1981 at Colstrip, Montana. The following spring, the site was fertilized with 24 treatments of N (0, 14, 28, and 56 kg N/ha), P (0, 112, and 168 kg P/ha), and K (0 and 28 kg K/ha) in factorial combination. Vegetational establishment was evaluated by measuring plant density, aerial biomass, canopy cover, and frequency by plant class and species. In addition, species diversity, evenness, and richness were calculated for each treatment.

After one growing season, P was the only fertilizer element to significantly affect vegetational establishment. Regardless of the level of N and K, P fertilization at 112 and 168 kg P/ha decreased density, aerial biomass, canopy cover, and frequency of warm season grasses. Legume aerial biomass and canopy cover were reduced by fertilization at 112 kg P/ha. The reduction of these two plant classes may be due to P fertilization increasing the competitive effect of other plant classes. Phosphorus fertilization increased the aerial biomass and canopy cover of annual forbs and annual grasses. Species diversity, evenness, and richness varied over the study site, but were not affected by fertilization.

It was recommended that P fertilization not be used the first growing season due to its negative effect on warm season grass and to an extent legume establishment. Nitrogen and K fertilization were not necessary for plant establishment under conditions of this study.

# INTRODUCTION

Since the late 1960's and early 1970's, America's need for energy has increased, while reliability of foreign sources of energy has decreased. Shortages of oil and gas during the 1970's resulted in long lines at gas stations and higher prices for all petroleum products. The Arab oil embargo during the early 1970's demonstrated the vulnerability of the United States to political blackmail. In order to prevent the United States from falling victim to the demands of oil and gas exporting countries, the Nixon administration initiated policies to achieve energy independence. Succeeding administrations adopted this goal of achieving energy independence for the United States.

An integral part of the government's policy for achieving energy independence was the encouragement of the development of western coal fields. Eastern Montana is one western region where coal development has expanded in the past decade. The Fort Union formation, a geological unit that encompasses much of eastern Montana, contains vast deposits of coal. Furthermore, the Powder River Region, a southern extension of the Fort Union Formation, is estimated to contain 240 billion tons of sub-bituminous coal (Packer 1974). Several strip mining operations have opened or expanded in eastern Montana during the past decade in response to the energy needs of the country. One such operation is Western Energy Company's Rosebud Mine located at Colstrip, Montana. Coal mining has taken place in the Colstrip area over the past fifty years, but in the last 10 years the operation has expanded considerably. Large area strip mining operations are expected to continue at Colstrip for the next several decades.

Strip mining of coal has resulted in the destruction of plant communities and disruption of soils. The Federal Surface Mining Control and Reclamation Act of 1977 required this land be reclaimed to a use equal to, or higher than, the use prior to mining. At Colstrip much of the mine land was formerly rangeland. The Montana Strip and Underground Mining Act of 1979 required the establishment on mine land of a suitable, permanent, diverse, vegetational cover consisting primarily of native species capable of feeding livestock and wildlife, withstanding grazing pressure, regenerating under natural conditions prevailing at the site, and preventing soil erosion to the extent achieved prior to mining.

Establishment of diverse, predominantly native plant communities is the goal of revegetation efforts at Colstrip (Coenenberg 1982). In order to achieve this goal, mine spoils are graded to approximate original contour and covered with material suitable for plant growth usually consisting of pre-mine topsoil and subsoil.

Establishment of diverse, native plant communities on mine soils may be affected by several factors. One factor is the nutrient status of the plant growth medium. Hodder et al. (1971) noted nutrient deficiencies on mine spoils at Colstrip could be corrected using fertilization. By limiting nutrient deficiencies, vegetational productivity of mine land can be increased to its maximum potential.

Little information is available in the literature concerning the effects of fertilization of mine soils on the establishment of native plant species. In particular, information is lacking on how fertilization affects the various components of newly established plant communities such as warm season grasses, or biennial forbs. An understanding of how fertilization affects initial vegetation establishment is important. The initial composition of the plant community may determine the successional direction the community will take. It is important to choose the fertilization regime that achieves the desired revegetation goals.

The objective of this study was to determine the first year response of a native species mixture to twenty-four fertilization treatments of nitrogen, phosphorus, and potassium in factorial combination on cover-soiled, regraded mine spoils at Colstrip.

The objective of this study was met by evaluating the various plant classes that comprised the newly established plant community. A fertilization treatment that improves establishment of the various plant components, provides high diversity for the overall plant community, and increases plant productivity to levels that meet post mine land uses; should be deemed an acceptable management practice. Management practices that adversely affect the establishment of one or more of these components could lower diversity of the total community to unacceptable levels. In addition, a management practice that increases the dominance of one species over others, could decrease plant community diversity.

# LITERATURE REVIEW

Plants need at least 16 elements in order to maintain vigorous growth and remain healthy. These elements are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl).

Often one or more of these essential nutrients is lacking in a soil in amounts necessary for adequate plant growth. Fertilization is used to correct nutrient deficiencies. In order to develop an effective fertilization program on mine land, one must understand how vegetation responds to fertilization, factors that influence plant response to fertilization, and elements of nutrient cycling.

## Vegetational Response to Fertilization

### Botanical Composition

Several studies on both rangeland and mine land noted that fertilization can change botanical composition of plant communities.

Fertilization of rangelands with N increased yield and/or cover for *Agropyron smithii* with corresponding decreases for *Bouteloua gracilis* (Goetz 1969, Power 1979, Rauzi 1978). These studies attributed the decreases in *B. gracilis* to competitive and shading effects of *A. smithii*. Rogler and Lorenz (1957) noted the grazing of study plots may eliminate these competitive effects. Fertilization of a southeastern Alberta grassland with N or N plus P generally increased basal area of cool season perennial grasses and weeds, while decreasing warm season grasses and sedges (Johnson et al. 1967). In eastern Montana, a ten year study showed species composition varied as much among years as among fertilizer treatments (Wight and Black 1979). Generally, N fertilization increased plant community composition of cool season grasses, reduced sedges, and at rates above 33 kg N/ha reduced *Bouteloua gracilis*. A study near Havre, Montana found annual fall application of N for 3 years increased production of total grass, *Stipa comata*, and *Agropyron smithii*, but decreased other grasses, forbs, and *Artemisia frigida* at cumulative rates above 336 kg N/ha (Houlton 1975). Meyn et al. (1976) reported N plus P fertilization of native range near Colstrip, Montana increased cover of annual grasses, forbs, and *Gutierrezia sarothrae* without affecting perennial grass production. In another study, *Agropyron smithii* and *Stipa viridula* production were not affected by fertilization with rates of 0 to 640 kg N/ha, however the highest rate increased production of *Bromus tectorum* and *Bromus japonicus* (White and Halvorson 1980). In Sidney, Montana no changes in plant community composition were found four years after a single application of N plus P in which the highest rates were 672 kg N/ha and 224 kg P/ha (Wight and Black 1978).

The effects of fertilization on the botanical composition of newly established vegetation on mine land have also been studied. A study at Decker, Montana compared seed mixtures consisting of all native species, all introduced species, and a combination of both species (Farmer et al. 1974). Fertilization increased the grass production of all the mixtures on topdressed and irrigated plots, however, introduced species significantly outproduced the natives.

DePuit et al. (1978) reported on the fertilization of several seed mixtures that included native and introduced species seeded separately and in combination. Native species did best at the zero or lowest fertilization rates, but were outproduced by introduced species at higher rates. In another study at Colstrip, Montana, DePuit and Coenenberg (1979) found N plus P fertilization increased stand composition of *Agropyron cristatum* and *Bromus inermis* while decreasing legumes.

## Cool Season Grasses

Fertilization with N or N plus P increased the response, establishment, yield, or density of several wheatgrasses (*Agropyron* spp.) on mine land and rangeland (Danielson et al. 1979, DePuit et al. 1978, Hodder et al. 1971, McGinnies and Nicholas 1980). Physiological changes in wheatgrasses due to fertilization have also been noted. Samuel et al. (1980) found N fertilization increased crude protein content of *A. smithii*. Goetz (1975) found the same trends for *A. smithii*, and reported that addition of P with N fertilization slightly increased crude protein content. With only P application, crude protein values were much lower. Black (1968) reported fertilization increased average crude protein production of vegetation in northeastern Montana on an *A. cristatum* site and a native range site composed of 55 percent *A. smithii*. Phosphorus fertilization also increased P content of plants regardless of N fertilizer rate. Nitrogen fertilization increased water use efficiency of these two sites 1.5 to 2.0 times, regardless of P rate. Fertilization affected mycorrhizal development in *A. trachycaulum* (Danielson et al. 1979). Nitrogen plus P fertilizer increased the rate of endomycorrhizae development and the presence of vesicles within roots.

Several studies examined the effects of fertilization on other cool season range grasses. Goetz (1969) found in southwestern North Dakota that N fertilization increased basal cover of *Calamovilfa longifolia*, while cover of *Stipa comata* decreased. Fertilization decreased percent composition of *S. comata* in western Montana (Klages and Ryerson 1965), and reduced its frequency in Colorado (Houston and Hyder 1975). In contrast, *S. comata* reached maximum yields at 336 kg N/ha (Wight and Black 1972), and reached maximum leaf lengths at 75 kg N/A in the Northern Great Plains (Goetz 1970). *Stipa comata* also increased in protein content with N fertilization (Goetz 1975). Black and Reitz (1969) found N plus P fertilization increased the seed yield and water use efficiency of *S. viridula* on a study conducted at Sidney, Montana. In contrast, Power (1979) found no effects on *S. viridula* due to fertilization, while Goetz (1975) found protein content increased. Wight and Black (1972) found *Koeleria cristata* yield unaffected by N and/or P fertilization, but other studies found it significantly reduced or eliminated (Houston and Hyder 1975, Power and Alessi 1971). *Poa secunda* generally responded to fertilization with increased yields (Baldwin et al. 1974), increased protein content (Goetz 1975), and increased leaf length (Goetz 1970). Houston and Hyder (1975) found heavy applications of N decreased yields of *P. secunda* about 88 percent. Nitrogen plus P fertilization increased yields of *Festuca idahoensis* in Oregon (Baldwin et al. 1974).

Nitrogen and N plus P fertilization increased yields of *Festuca scabrella* when applied at rates up to 1015 kg N/ha and 860 kg P/ha, while fertilization at levels of 350 kg N/ha alone or with 290 kg P/ha killed *F. rubra* (Johnston et al. 1968). Fertilization also increased yields of *Bromus inermis* in this Canadian study.

Warm Season Grasses

Few studies have documented the response to fertilization of seed mixtures or plant communities consisting almost entirely of warm season grasses. Warnes and Newell (1969) concluded that fertilization during the first growing season had no benefit on establishment of *Panicum virgatum*, *Sorghastrum nutans*, *Bouteloua curtipendula*, *Andropogon gerardii*, and *Schizachyrium scoparium*. Nitrogen fertilization tended to increase biomass production of weeds, while decreasing warm season grasses. Fertilizer applied after the first growing season, increased forage yield from 10 to 243 percent depending on number of years after establishment, soil fertility, and moisture conditions during year of harvest. In another study, *Andropogon gerardii*, *Panicum virgatum*, *Sorghastrum nutans*, and *Bouteloua curtipendula* were seeded and then fertilized two years after establishment with annual applications of N and alternate years with P (Rehm et al. 1972). Fertilization increased forage yields of all species in three out of four years, and at the end of four years *A. gerardii* and *B. curtipendula* were the dominant species on all plots. Fertilization increased forage production and protein content of leaves on a sandy range site in Texas for *Andropogon hallii*, Schizachyrium scoparium, Aristida purpurea, Bouteloua curtipendula, Sporobolus cryptandrus, and other species (Pettit and Deering 1974). Bryan and McMurphy (1968) seeded several warm season species and then fertilized with N and P. Fertilization reduced density of Panicum virgatum due to competition from weeds. With weed control P. virgatum production increased on fertilized plots. Andropogon gerardii, Eragrostis curvula, and Bothriochloa ischaemum var. ischaemum were not significantly affected by fertilization on the basis of stand establishment.

Some studies have reported the effects of range fertilization on warm season grasses. Rauzi et al. (1968) found fertilization of native rangeland in Wyoming did not affect warm season grasses, and variation in yield was a function of time instead of treatment. In another Wyoming study, high levels of N fertilization decreased Buchloe dactyloides yields from 9 percent to a trace over a five year period (Rauzi 1978). Fertilization of true prairie near Manhattan, Kansas decreased N free extract and increased crude fiber, lignin, and ash of Andropogon gerardi and Schizachyrium scoparium (Allen et al. 1976).

Bouteloua gracilis generally responds negatively to fertilization, but exceptions exists. Goetz (1970) found N fertilization increased leaf length, but Wight and Black (1972) found no effects on B. gracilis from N plus P fertilization. In a western North Dakota study, N plus P fertilization increased protein content of this plant (Goetz 1975). Without N fertilization, applications of P decreased protein content below levels of unfertilized plants. This occurred in the early part of the growing season, but later in the season protein contents were higher in the fertilized plants.

Sedges

Limited data existed for response of sedges (Carex spp.) to fertilization. Carex filifolia increased in basal cover with N fertilization at rates between 33 and 100 kg N/ha (Goetz 1969). Nitrogen fertilization also increased leaf length (Goetz 1970) and protein content (Goetz 1975).

Legumes

Several studies found legumes negatively affected by fertilization. Nitrogen fertilization reduced legume cover (DePuit et al. 1978), growth (Blaser and Brady 1950), and yield (Cooper 1975). Cooper (1969) stated that N fertilization decreased legumes by increasing the competitive ability of grasses. Epstein (1972) noted decreased nodule formation on legume roots under high levels of soil N. Blaser and Brady (1950) demonstrated that the addition of K to N fertilizer increased productivity of legumes. Addition of P fertilizer is well known for its generally positive effects on legumes (Cooper 1969). Howard et al. (1977) found N plus P fertilization generally favored improved growth of alfalfa. Nitrogen fertilization reduced frequency of Astragalus shortianus and eliminated Lathyrus polymorphus (Houston and Hyder 1975). Fertilization with N and P reduced infection rate of mycorrhizae in Trifolium hybridum though total infected root length remained unchanged (Danielson et al. 1979).

## Forbs

Kilcher et al. (1965) found for the first two years after a single application of N and/or P fertilizer, weed yields increased. In North Dakota, N fertilization increased basal cover of forb species (Goetz 1969). In Colstrip N, P, and K fertilization of seeded mine lands significantly increased forb production, with Salsola kali as the dominant species (Holechek 1976). Nitrogen and P fertilization reduced basal cover of Selaginella densa, an undesireable species (Smoliak 1965). Fertilization of mixed grass plains with nitrogen increased frequency of Lepidium densiflorum, Chenopodium leptophyllum, but decreased Phlox hoodii (Houston and Hyder 1975).

## Shrubs and Half Shrubs

Nitrogen and N plus P fertilization increased yield of Atriplex canescens (Aldon et al. 1976, Aldon 1978, Howard et al. 1977), but emergence and initial growth remained unaffected (Aldon and Springfield 1973, Aldon et al. 1975). Fertilization with N and/or P increased height and yield of Artemisia frigida (Goetz 1970, Wight and Black 1972), but all rates of N in another study reduced its frequency (Houston and Hyder 1975).

## Factors Affecting Vegetational Response to Fertilization

Several studies identified factors that affect plant response to fertilization on both range and mine land. Goetz (1970) found that the vegetational response to fertilization varied by range site, season, plant species, and amount of fertilizer applied. Other factors that affected plant response included soil type, soil fertility level, soil and air temperature, and amount and distribution of precipitation during the growing season (Rauzi et al. 1968). For the purpose of this review, factors that affect the response of vegetation to fertilization are broken into biological, nutrient interactions, soil properties, and management techniques.

Biological

The presence or absence of microorganisms can have an effect on vegetational response to fertilization. Microorganisms caused a number of physio-chemical changes on mine spoils including increasing the amount of available nutrients (Cundell 1977). This was especially true for N and P. Cundell (1977) and Mosse (1973) stated that vesicular arbuscular mycorrhizae may be important in P deficient soils by increasing the phosphate absorbing surface on roots of grasses and other perennials. Cundell (1977) also suggested azotobacteria may be important in the rhizosphere of plants growing on spoils low in nutrients.

Nutrient Interactions

Several studies have shown that an excess or deficiency of one nutrient in a soil system can change the response of vegetation to fertilization with other nutrients.

The influence of N fertilization on increasing the P uptake by plants is well established (Riley and Barber 1971). Olson and Dreier (1956) found that N fertilization stimulated wheat and oat uptake of P fertilizer over a wide range of soil conditions. Two studies on mixed grass prairie in North Dakota demonstrated that greater yields occurred when both N and P were applied together, than when each applied as separate treatments (Lorenz and Rogler 1972, 1973). In a study evaluating response of vegetation to fertilization on selected native grassland sites in western Canada, combinations of N and P fertilizer produced greater biomass yields on all but two sites, when compared to N and P applied separately (Kilcher et al. 1965). Johnston et al. (1968) also found for both a seeded and native range site in western Canada, that N and P applied together produced greater total vegetation yields than when each was applied separately. Black and Wight (1972) found that though P fertilization by itself did not increase total protein content of the forage, when applied in combination with N it increased protein content approximately 30 percent. Nitrogen and P applied in combination also increased percent plant P content and recovery of N in total forage. In contrast, Goetz (1975) found P applied with N did not increase protein content of total vegetation, when compared to N fertilized separately. Riley and Barber (1971) stated that $NH_4$-N was superior to $NO_3$-N in stimulating P uptake by soybeans. Another study on cereal grain plants found $NH_4$-N increased P uptake by the plants, but $NO_3$-N had little effect (Rennie and Soper 1958).

Interactions between nutrients other than those between N and P can affect vegetational response to fertilization. In corn, uptake of Zn appeared to be inhibited by applied P to the extent where levels of Zn critical for growth were reached (Langin 1962). Bains and Fireman (1964) found for five different species of crop plants, that an increase in exchangeable sodium (Na) in the soil generally increased uptake of Na, N, and Mo, and decreased uptake of Ca, K, S, Mg, Cu, Zn, B, and Cl.

Soil Properties

Several properties of soils influence plant response to fertilization. Some of these properties include soil moisture, soil temperature, topsoil depth, and soil pH.

Bauer et al. (1978a) stated that moisture has an overriding effect on plant growth and yield, and on the amount of nutrient needed to correct a deficiency. In contrast, Klages and Ryerson (1965) hypothesized that soil fertility may be a greater limiting factor than moisture on total range production, even in coarse-textured, droughty soils. Greater soil moisture content increased plant response to N and/or P fertilization by increasing plant N uptake (Power 1967) and yields (Bauer et al. 1967, Smika et al. 1965, Wight and Black 1979). Nitrogen fertilization did not affect botanical composition of a rangeland site in Montana during the years of adequate precipitation, however growth of weedy species was stimulated during years of low precipitation (Klages and Ryerson 1965). In a rangeland study, fall soil moisture had the greatest influence on the vegetation yield of unfertilized and P fertilized plots, while June precipitation influenced the N and N plus P fertilized plots (Johnston et al. 1969). Lauenroth and Dodd (1979) found N fertilization and irrigation favored native legumes growing in the shortgrass prairie of northeastern Colorado, but in following growing seasons density of legumes decreased. On plots receiving only irrigation, legume density remained high.

Soil moisture content may affect vegetational response to N fertilization by affecting the process of nitrification. Nitrification involves the oxidation of $NH_4$-N to $NO_3$-N. Many forms of N fertilizers contain $NH_4$-N, and in order for N to become available to the plants, nitrification must take place. Any factor such as soil moisture content that influences nitrification, will affect the amount of N available to plants from ammonical fertilizers.

Several studies found nitrification affected by the soil moisture content. Incubation studies by Parker and Larson (1962) revealed that greatest nitrification occurred at soil moisture tensions of 0.7 bars. As soil moisture tension decreased from 0.7 bars, nitrification decreased. For tensions above 0.7 bars, nitrification was not increased. Stanford and Epstein (1974) discovered highest nitrification rates occurred at moisture tensions between 0.3 to 0.1 bar in a study that investigated nine different soils of varying texture. In another study, maximum nitrification took place at soil moisture tensions between 0.5 and 0.15 bars (Miller and Johnston 1964). These authors concluded that deficient moisture at higher tensions, and poor aeration at lower tensions limited nitrification. In North Dakota soils under incubation, nitrification rates decreased as soil water contents decreased between 0.2 and 15 bars (Reichman et al. 1966).

Soil moisture content may also have an effect on plant response to P fertilization. Beaton and Read (1963) reported that 2.0 bars of moisture tension favored uptake of P in oats, while lowest uptake occurred at 0.4 bars. They also noted water soluble sources of P fertilizer were most sensitive in affecting uptake of P in plants when soil moisture content changed.

Several studies indicated soil temperature can affect the response of vegetation to N fertilization by influencing nitrification. In aerated soils, most nitrification occurs between 0° and 35° C (Stanford et al. 1973). Nitrification ceases completely at 45° C and 0° C. In laboratory studies, Parker and Larson (1962) found that a 2° C increase in temperature caused an increase in the rate of nitrification in the 16-20° C range. Between 25° C and 30° C, changes in rate of nitrification were not as evident with small changes in temperature. Stanford et al. (1973) found nitrification increased two fold for each 10° C increase in temperature.

Influences of soil temperature on vegetational response to fertilization have been observed. In wheat and barley, temperature was negatively correlated with yield responses from N fertilization (Bauer et al. 1967). In oats greatest uptake of fertilizer P in the mono and diammonium phosphate form occurred at 5° C, when compared to uptake at 16° or 27° C (Beaton and Read 1963). No significant differences in P uptake were noticed between the 16° or 27° C levels.

Studies have shown $O_2$ content of the soil can affect nitrification. Generally, as $O_2$ content increased from 0 to 20 percent, nitrification increased in curvilinear fashion (Amer and Bartholomew 1951). At least 0.2 to 0.4 percent $O_2$ was needed for nitrification to occur in a soil.

Depth of topsoil placement on coal mine spoils has been shown to affect plant response to fertilization. When topsoil was placed at thicknesses of 0, 2, 6 and 12 inches on spoil material, fertilization increased the response of vegetation over controls, but the magnitude of increase varied with depth (ARS and NDAES 1977). In greenhouse experiments, total herbage, total root production, and total biomass of *Agropyron intermedium* increased as topsoil thickness above spoil material increased from 0 to 30 cm (McGinnies and Nicholas 1980). Fertilization increased total production an average of 89 percent over the non-fertilized treatments. Nitrogen fertilization also increased root mass an average of 46 percent in the topsoil and 87 percent in the spoil material.

Soil pH has been found to affect the amount of soluble P in soils. Acid soils tended to increase the amount of $H_2PO_4^-$ in the soil, while soils of pH 7.0 and above had greater amounts of $HPO_4^{-2}$ (Tisdale and Nelson 1975). Phosphorus was generally most available to plants between pH's of 5.5 and 7.0.

## Management Techniques

Timing of fertilization can affect vegetational response. In Arizona, desert grassland plots fertilized during the latter part of the rainy season increased grass production when compared to plots fertilized earlier in the season (Stroehlein et al. 1968). Latter fertilization also increased protein content of plants on two of the sites. Samuel et al. (1980) working in Wyoming found yield and protein content of plants increased linearly with fall applied N, but increased non-linearly with spring applications of N at the same rates. Spring applied N also produced higher yields, crude protein contents, and frequency of grazing by cattle, than fall fertilization at 22 kg N/ha. No differences were found between the fall and spring applications at 34 kg N/ha.

Source of fertilizer material may also affect the manner in which vegetation responds to fertilization. Beaton and Read (1963) measured short term P uptake by oats from several fertilizer sources. They found mono-ammonium phosphate produced the greatest P uptake and anhydrous dicalcium phosphate the least. In one long term experiment in which several sources of P fertilizer were used, the source causing the greatest uptake of P in plants varied with soil type and plant species (Ensminger and Pearson 1957). Power et al. (1973) reported greatest recovery of fertilizer N from corn tops occurred with $NH_4NO_3$ when compared to other materials including calcium nitrate and urea. Power (1979) tested $NH_4NO_3$, urea formaldehyde, and three different sulfur coated ureas, and found responses by vegetation varied with the fertilizer material used.

In southeastern Montana, mulching had an affect on vegetational response to fertilization (Farmer et al. 1974). On spoils, fertilized mulch plots had greater grass yields than unmulched plots with the same fertilizer rates. On spoils covered with 8 inches of cover-soil, fertilization had no effect on seedling emergence of unmulched plots, while seedling density decreased on mulched plots.

Method of placement of fertilizer in a soil system has an affect on how plants will respond to treatment. Injury to germinating seeds can be caused by placement of N and K fertilizer directly with the seed (Tisdale and Nelson 1975). This injury was due to restriction of available moisture or toxicity caused by an increase in concentration of soluble salts by the fertilizer. Injuries can be lessened or eliminated by other methods of fertilizer application such as broadcasting or selection of non-ammonical fertilizer sources. Moore et al. (1968) compared drill placement of fertilizer P with broadcasting on sub-irrigated meadows in Nebraska. They found drill placement of fertilizer reduced plant density and yield when compared to the broadcast method. The decreases were attributed to the drying out of sod near the drill rows. Percent P in forage, root activity of legumes, and utilization of fertilizer P by plants was lower under drill treated sites. Incorporation of fertilizer P into the soil increased vegetation response when compared to P applied on the surface (Tisdale and Nelson 1975). Fertilizer P is relatively immobile compared to other nutrients, and incorporation allows plant roots to come into direct contact with fertilizer P.

## Nutrient Cycling in Mine Land

The literature on nitrogen cycling in range and mine land is more extensive than that for P and K cycling. This section focuses primarily on N cycling. It is not intended to be a complete summary on nitrogen cycling, but the important aspects are covered.

Addition of fertilizer N has been shown to increase plant available N in soils (Houston and Hyder 1975, Power 1972b). Fertilizer N enters and functions in the nitrogen cycle through various processes such as nitrification, plant uptake, and loss.

Soil organic matter is important in supplying plant available nitrogen through mineralization (Tisdale and Nelson 1975). On mine land, adequate amounts of organic matter are often lacking to provide sufficient nutrients for vegetational growth. Bauer et al. (1978b) noted that a characteristic common to all spoil material was the lack of organic matter. In cases in which topsoiling practices were used, the occurrence of nutrient deficiencies may vary depending on the suitability and thickness of the applied cover-soil. The organic matter content of stockpiled topsoil may decrease with length of storage (Argonne National Laboratory 1979). Parkinson (1979) suggested that addition of waste materials rich in cellulose, lignin, chitin, etc. could be a means of increasing organic matter content of spoil material, provided decomposing microorganisms were also introduced. Omodt et al. (1975) estimated it would take at least 350 years for organic matter on mine land spoils to naturally accumulate to levels found in undisturbed soils of western North Dakota. To raise organic matter levels to 1 percent in mine spoils, it was calculated 291 metric tons of manure/ha applied annually for a forty year period would be needed. Due to the impracticality of applying this much manure, it was concluded the salvaging and redistribution of topsoil on spoils would be more practical for maintaining organic matter levels of mine soils.

Losses of N from the nitrogen cycle in mine land are divided into leaching, biological, gaseous, and geological. In Great Britian, nitrogen was the main nutrient lost by leaching on mine land (Marrs and Bradshaw 1980). Losses of N, P, Ca, and Mg were greater than imputs from natural sources. In the Northern Great Plains, leaching of $NO_3$-N was of little concern because of insufficient precipitation (Power 1972a). Power and Alessi (1971) found no accumulation of $NO_3$-N from leaching below 90 cm in a grassland system. Young and Rennick (1982) noted supplemental irrigation on mine land at Colstrip caused leaching of $NO_3$-N to occur. The influence of irrigation on increasing $NO_3$-N loss from mine land should not be ignored.

Biological losses of plant available N can occur in mine land under certain circumstances. Berg (1980) noted addition of organic matter such as straw mulch could decrease plant available soil $NO_3$-N. Reuszer (1957) stated that N was needed by microorganisms for the decomposition of added organic material. If the added organic material contains insufficient quantities of N for its own decomposition, microorganisms will utilize indigenous or fertilizer N in the soil (Tisdale and Nelson 1975). An indication of whether or not organic matter contains sufficient quantities of N for its own decomposition is its carbon/nitrogen ratio (C/N). As a generalization microorganisms will utilize N from the soil to decompose organic matter with C/N ratios above 30. Organic matter with C/N ratios below 30, have sufficient N to meet the needs of microbial decomposers, while material with C/N ratios below 20 have excessive amounts of N that can be released into the soil system through microbial decomposition.

Gaseous losses of N can occur through three mechanisms: denitrification, chemical reactions involving nitrites, and volatile losses of ammonia gas (Tisdale and Nelson 1975). Conversion of $NH_4$-N to $NO_3$-N occurred in exposed Palocene shales on mine lands, and the $NO_3$-N subsequently lost possibly due to denitrification (ARS and NDAES 1975). Urea applied via broadcast methods on Bromus inermis was suspected of being lost to the atmosphere, since only 47 percent of the applied N was accounted for in the soil and plants (Power et al. 1973). Volatilization of $NH_4$-N placed on the surface of alkaline soils may also take place (Tisdale and Nelson 1975).

Geological losses of fertilizer material may also occur in mine land. Ammonium added as fertilizer to spoil material in east central Texas was converted to non-exchangeable $NH_4$-N (Hons and Hossner 1979). The mine soil had a non exchangeable $NH_4$-N retention capacity that ranged from 4.1 to 7.8 meq $NH_4^+$/100 g, while lignite had a capacity of 46 meq $NH_4^+$/100 g.

# MATERIALS AND METHODS

## Experimental Design

The study area was located in Mining Area A of Western Energy Company's Rosebud Mine at Colstrip, Montana, and covered approximately 2,590 $m^2$.

Spoil piles on the study site and adjacent areas were graded and leveled. Coversoil was placed on the leveled spoils in late September 1981. Average cover-soil depth was between 60 and 70 cm, but ranged from 46 to 100 cm. Cover-soil was placed on the site with two scrapers pulled by a four wheel drive tractor. Soil compaction may have occurred during this process. In addition, water was sprayed on the cover-soil after every few passes of the scraper for dust control. After placement of cover-soil, the area was chisel plowed twice to a depth of 25 cm and disced once on the contour in early October to alleviate compaction. The cover-soil material, a mixture of both topsoil and subsoil, was obtained from a storage pile constructed in 1976 (J. Cundiff, personal communication).

Seedbed preparation commenced on November 3, 1981. At this time the study site was chisel plowed twice, disced and harrowed. The northern third of the study site was accidently ripped prior to seedbed preparation. To correct this situation, the ripped areas received an additional chisel plowing and discing.

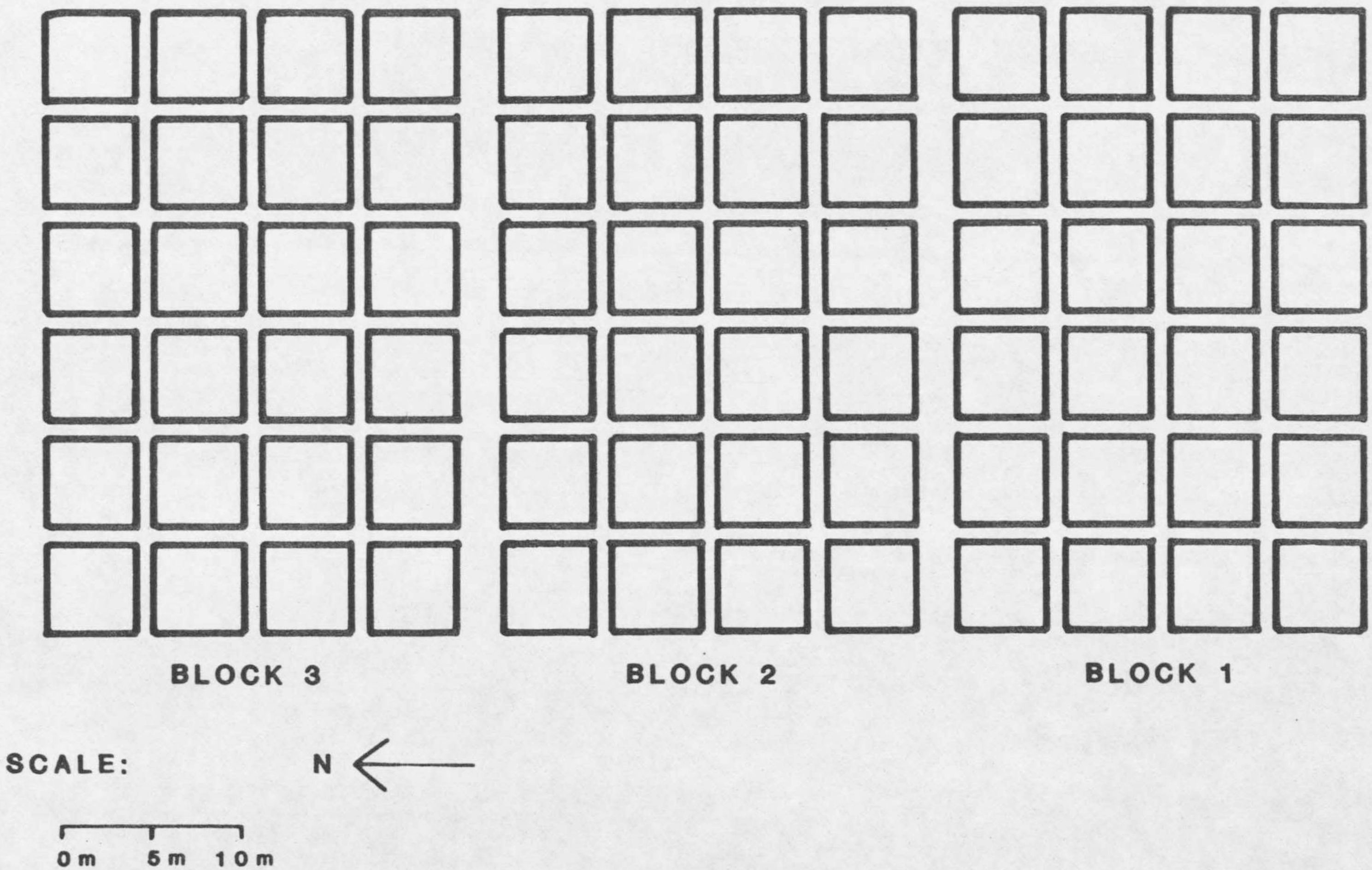
Three 35 by 23 m blocks were laid out in parallel with the long side of the blocks running approximately east to west. Blocks were numbered from 1 to 3 running from south to north. Figure 1 shows the layout of blocks and experimental plots. A buffer zone of 2.5 m separated each block. Within each block twenty-four, 5 by 5 m plots were placed in four rows of six and separated by a 1 m buffer zone. Plots were numbered by rows within each block from south to north. Numbering began in each block with the plot located in the southwestern corner. All plots were consecutively numbered from 1 to 72 starting with Block 1.

Each plot was broadcast seeded by hand on November 3, 1981 to achieve a fall dormant seeding. Table 1 lists the plant species and seeding rates used on all study plots. All species, except *Astragalus cicer* are considered native to the Northern Great Plains. A sheep's foot cultipacker was pulled over the site after seeding to ensure a firm seed bed.

Table 1. Seed mixture and rates used on fertilization study.

| Scientific name | Common name | kg/ha pure live seed | # seeds/ $m^2$ |
|---|---|---|---|
| *Agropyron dasystachyum* | Critana thickspike wheatgrass | 3.5 | 118 |
| *A. smithii* | Rosana western wheatgrass | 4.7 | 118 |
| *A. trachycaulum* | Revenue slender wheatgrass | 3.6 | 118 |
| *Andropogon hallii* | Sand bluestem | 6.8 | 118 |
| *Bouteloua curtipendula* | Pierre sideoats grama | 1.1 | 118 |
| *B. gracilis* | Lovington bluegrama | 0.8 | 118 |
| *Calamovilfa longifolia* | Goshen prairie sandreed | 1.1 | 65 |
| *Panicum virgatum* | Pathfinder switchgrass | 2.1 | 118 |
| *Stipa viridula* | Lodorm green needlegrass | 2.4 | 118 |
| *Astragalus cicer* | Lutana cicer milkvetch | 4.3 | 118 |
| *Petalostemon purpureum* | Kaneb purple prairie clover | 3.8 | 237 |
| *Atriplex canescens* | Wytana fourwing saltbush | 3.6 | 43 |
| | total | 37.8 | 1407 |

Figure 1. Field design.



A randomized block design with three replications was used for this study. Twenty-four combinations of fertilization rates were tested and randomly assigned to plots within each block. The fertilizer treatments consisted of four rates of nitrogen (0, 14, 28, and 56 kg/ha), three of phosphorus (0, 112, and 168 kg/ha), and two of potassium (0 and 28 kg/ha) in complete factorial combination. Table 2 lists the twenty-four fertilization treatments by codes. Throughout the rest of this thesis, fertilization treatments will be referred to by these codes.

Table 2. Fertilizer treatment combinations.

| Treatment | | | Treatment | | | Treatment | | |
|---|---|---|---|---|---|---|---|---|
| NO | PO | KO[a] | N14 | P168 | KO | N28 | P168 | K28 |
| NO | P112 | KO | N14 | P112 | K28 | N28 | PO | K28 |
| NO | P168 | KO | N14 | P168 | K28 | N56 | PO | KO |
| NO | P112 | K28 | N14 | PO | K28 | N56 | P112 | KO |
| NO | P168 | K28 | N28 | PO | KO | N56 | P168 | KO |
| NO | PO | K28 | N28 | P112 | KO | N56 | P112 | K28 |
| N14 | PO | KO | N28 | P168 | KO | N56 | P168 | K28 |
| N14 | P112 | KO | N28 | P112 | K28 | N56 | PO | K28 |

[a]Numbers following elemental designation refer to application rate (N = 0, 14, 28, and 56 kg/ha; P = 0, 112, and 168 kg/ha; K = 0 and 28 kg/ha).

The source of nitrogen was ammonium nitrate (34-0-0). Phosphorus was applied in the form of triple superphosphate (0-44-0), and potassium in the form of potassium chloride (0-0-60). The experimental plots were fertilized with their respective mixtures on April 29, 1982. The fertilizer was uniformly broadcasted over the plots by hand. Only one person fertilized plots in a block to ensure consistency of application within each block.

## Vegetation Sampling

A number of vegetational parameters were estimated on this study. These parameters included density, aerial biomass, canopy cover, frequency, diversity, evenness, and richness.

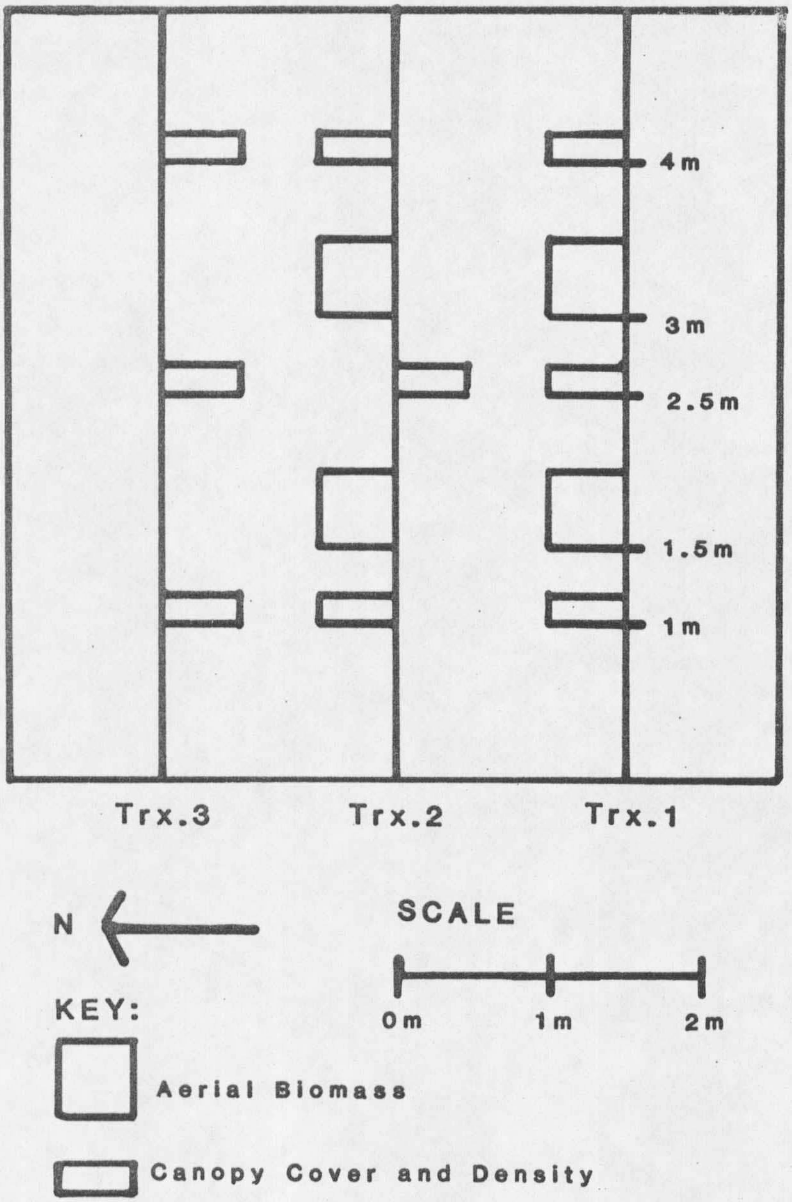
Figure 2 illustrates the sampling scheme used in each plot. Three parallel transects were placed in each plot 1.5 m apart. The transects ran parallel to the east/west sides of the plot, and the two outer transects were placed 1 m from the edges. The west end of each transect was permanently marked.

### Density

Plant density was counted on the experimental plots on May 21 and 22, and again between July 6 and 9, 1982. Six, 20 x 50 cm sampling frames were used in each plot during May. Transects 1 and 3 each had 3 frames located 1.5 m apart (Figure 2). Density was defined as the number of individual plants per sample frame. For species with a bunch or tillering growth habit, a plant was considered an individual if there was a gap of at least 1 cm between its base and the base of another plant. Plants were counted on a species basis when identifiable, or placed into plant classes. Nomenclature for scientific names of plant followed U.S.D.A. (1982).

The same sampling procedures for May were used for the July measurements except that 3 frames were added to Transect 2. Field observations in late June indicated six sample frames were not enough to include the majority of plant species found in each plot. Only approximately 50 percent of the species located in each plot were

Figure 2. Vegetation sampling design for each experimental plot.



found within the six sample frames. Preliminary sampling was conducted in late June to determine the number of sample frames needed to include the majority of plant species found on the study plots. The results of the preliminary sampling are shown in Figure 3. Cumulative number of plant species were graphed against number of sample frames. For the sample plot, 10 sample frames were optimal. The 10 frames included 12 of the 16 species found on the plot. Due to physical limitations of the study plot, only nine sample frames were used.

## Aerial Biomass

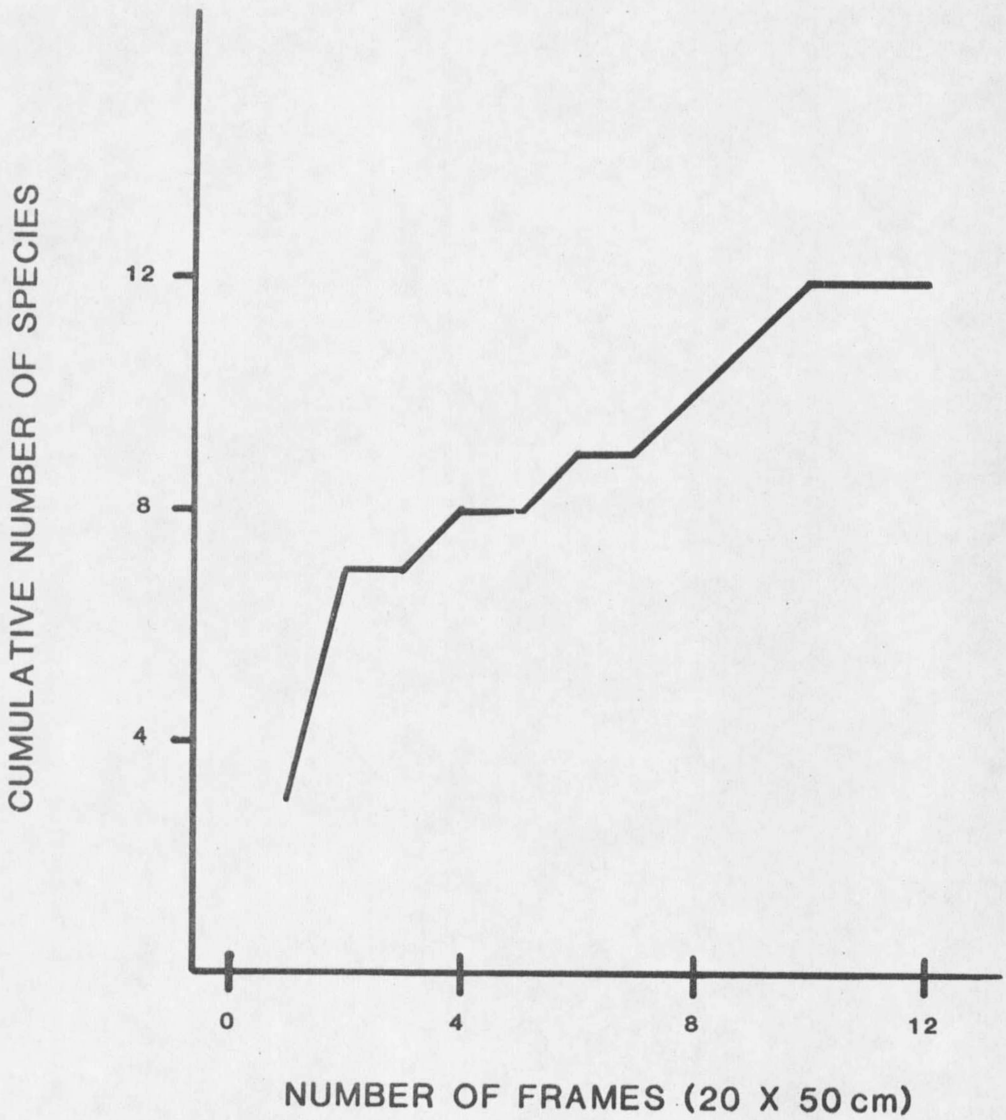
Vegetation was clipped for aerial biomass between July 20 and 25, 1982 for cool season perennial grasses, annual grasses, forbs, *Salsola kali*, legumes, and shrubs. Warm season grasses were clipped on August 12 and 13, 1982. The vegetation was clipped at time of maximum aerial biomass production.

A total of four, $1/4 m^2$ frames were used to sample each plot. Two frames were located on both Transects 1 and 2, and located 1.5 m apart ( Figure 2). Standing vegetation was clipped to within 1 cm of ground level. The clipped vegetation was oven dried at $67^{\circ}$ C for 48 hours, and then weighed to the nearest tenth gram.

## Canopy Cover

Canopy cover was recorded for all plots between July 20 and 25, 1982. Nine 20 x 50 cm sampling frames were used for each plot. Three sample frames were located 1.5 m apart on each transect (Figure 2). Canopy cover was read for each plant species in a sample by methods

Figure 3. Preliminary sampling to estimate number of frames needed.



described by Daubenmire (1959). Daubenmire's cover classes were modified for this study as listed in Table 3.

Table 3. Cover classes used for canopy cover sampling.

| Cover class | Range of percent canopy cover | Midpoint of cover class |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 0 > 5 | 2.5 |
| 3 | 5 - 10 | 7.5 |
| 4 | 10 - 20 | 15 |
| 5 | 20 - 30 | 25 |
| 6 | 30 - 40 | 35 |
| 7 | 40 - 50 | 45 |
| 8 | 50 - 60 | 55 |
| 9 | 60 - 70 | 65 |
| 10 | 70 - 80 | 75 |
| 11 | 80 - 90 | 85 |
| 12 | 90 - 95 | 92.5 |
| 13 | 95 > 100 | 97.5 |
| 14 | 100 | 100 |

Frequency

Frequency was calculated from canopy cover data, and defined as the percentage of canopy cover sample frames in which a particular plant species occurred. Frequency for a plant species was based on a total of 27 sample frames located in the three plots representing a particular fertilization treatment.

Diversity

Diversity was calculated for each fertilization treatment using the Shannon Function. Pielou (1975) listed the Shannon Function as:

$$H' = \sum_{i=1}^{S} P_i \log P_i$$

where Pi is the proportion of the plant community belonging to the ith species and S the number of species present in the sample. The portion of the total percent canopy cover of each plant species in a fertilization treatment represented the $P_i$ values.

Evenness

Evenness was defined as the distribution of total plant community canopy cover among the individual plant species. The evenness index used was described by Odum (1971) as: $e = H'/\log S$, where $H'$ is the calculated Shannon Funtion and S the number of species found in the sample.

Richness

Richness was defined as the total number of individual plant species found in each fertilization treatment. Richness was based on the species found in the canopy cover data for each treatment.

## Soil Sampling

Samples for baseline soils characterization were taken on October 22 and 23, 1981. One composite sample was taken per block and broken into depth intervals of 0-30 cm, 30-60 cm, and 60-120 cm. Each composite consisted of fifteen, 4.8 cm diameter cores taken with a Giddings probe at randomly picked locations within each block. The composites for each depth interval and block were thoroughly mixed, placed in separate sample bags, and immediately frozen. After transport, the frozen samples were immediately thawed, air dried for 72 hours, then ground.

Soil samples for each block and depth interval were analyzed for percent total N, $NO_3$-N, extractable P and K, percent organic matter, electrical conductivity (EC), sodium absorption ratio (SAR), pH, exchangeable Ca, Mg, and Na; cation exchange capacity, and particle size. Total N was determined by the semimicro Kjeldahl digestion/distillation method described by Black (1965). Nitrate was analyzed at the Montana State University Soil Testing Laboratory which used procedures based on the work of Doner et al. (1973), Sims and Jackson (1971), and West and Ramachandran (1966). Extractable P and K; cation exchange capacity; exchangeable Ca, Mg, and Na; and SAR were determined by methods described by Sandoval and Power (1977). Sims and Haby (1970) described methods used for determining percent organic matter. An aliquot from a saturated soil paste for each sample was used for determining pH and EC. Particle size analysis was conducted using the hydrometer method described by Black (1965). In addition C/N ratios were calculated for each soil sample using percent total N and percent organic matter content. Organic C content was assumed to be 58 percent of the organic matter content (Brady 1974).

Post fertilization soil sampling was conducted on October 11, 1982. Two sets of soil samples were taken. The first set involved compositing soil taken from plots containing all combinations of P and K fertilization for a specific level of N. This was done for all 4 levels of N in each block for the depth intervals of 0-15 cm and 15-30 cm. This set of soil samples was analyzed for total N, $NO_3$-N, and percent organic matter. The second set of samples consisted of compositing soil taken from plots containing all combinations of N and K for a specific level of P. This was done for all levels of P in each block for the depth interval of 0-15 cm. This set of samples was analyzed for extractable P. Preparation and analysis of soil samples did not differ from procedures used for baseline soil sampling except that soil samples were taken with the use of an Oakfield probe, two cores were taken randomly from each of the appropriate plots to form the composite, and $NO_3$-N was analyzed using methods described by Richards (1954). Haby and Larson (1976) found the two techniques of $NO_3$-N analysis used on this study were highly correlated ($r^2$=0.94). The use of the two techniques should not affect comparision of $NO_3$-N levels.

Soil moisture data were obtained with a neutron probe. McHenry (1963) described the theory and application of the neutron probe in measuring soil moisture. Two neutron probe access tubes were installed adjacent to the study site. One access tube was located north of the site, and the other to the south. The access tubes were installed to a depth of 160 cm. Neutron probe readings were taken once a month during the growing season at 15 cm intervals to a depth of 90 cm, then at 30 cm intervals to a depth of 150 cm. Field generated data were converted to percent volumetric soil moisture content by use of factory calibration equations.

## Statistical Analysis

### Vegetation

Analysis of variance (ANOVA) methods were used to analyze the density, aerial biomass, and canopy cover data.

For density the plant classes of cool season perennial grasses, warm season grasses, annual grasses, annual forbs, biennial forbs, perennial forbs, legumes, shrubs, and total vegetation were analyzed. A five factor ANOVA consisting of time, blocks, N, P, and K was used to evaluate the data. Two mean square errors were calculated for the density data. The first error was calculated by pooling the sum of squares for all interactions involving blocks without time, and utilized in calculation of the F statistic of all main effects and nutrient interactions not involving time. The second error term was calculated by pooling the sum of squares for all interactions involving both time and blocks, and utilized in calculating the F statistic for time and all interactions involving time.

Analysis of variance was conducted on aerial biomass data for cool season perennial grasses, warm season grasses, annual grasses, forbs, *Salsola kali*, legumes, shrubs, and total vegetation. For canopy cover the plant classes of cool season perennial grasses, warm season grasses; annual, biennial, and perennial forbs; legumes, shrubs, and total vegetation were analyzed. A four factor ANOVA consisting of blocks, N, P, and K was conducted on the aerial biomass and canopy cover data. The error was calculated by pooling the sum of squares of all interactions involving blocks.

The null hypothesis tested in the study was that the mean responses of a particular data parameter for a plant class are equal for all fertilization treatments. Significance was defined as the rejection of the null hypothesis with a probability greater than 95 percent ($p<0.05$). Rejection of the null hypothesis with a probability greater than 99 percent ($p<0.01$) was also noted.

Soils

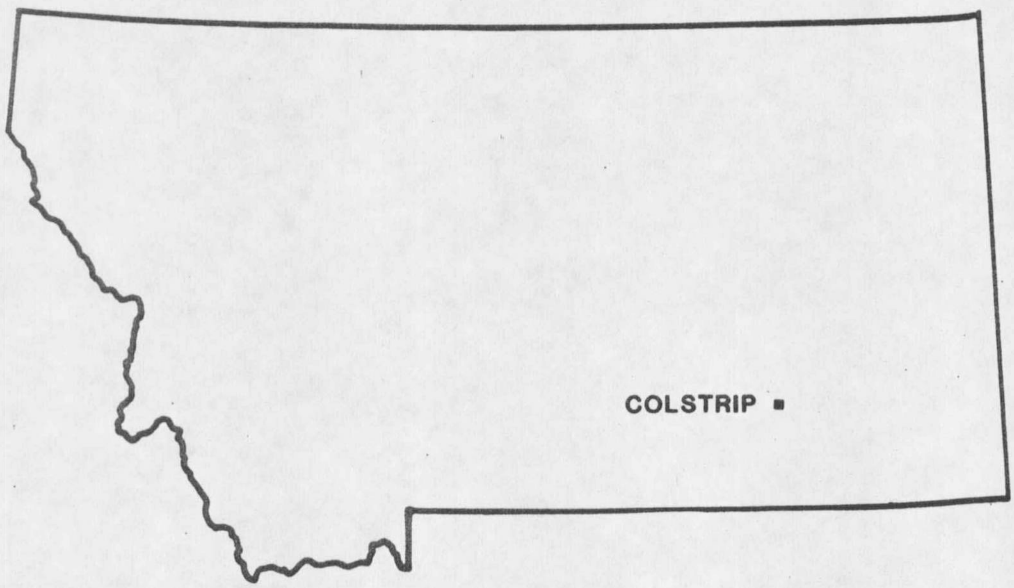
Post fertilization soil data taken in October 1982 were analyzed using ANOVA. Total N, $NO_3$-N, percent organic matter, and extractable P were each analyzed using one factor ANOVA. Each block was considered a replication. Significance and testing of the null hypothesis were conducted in the same manner described for vegetation.

# STUDY SITE DESCRIPTION

## Location

The study site was located in Mining Area A of Western Energy Company's Rosebud Mine at Colstrip, Rosebud County, Montana (Figure 4). Colstrip is approximately 48 km south of Forsyth, MT at an elevation approximately 980 m above sea level (Meyn et al. 1976). The legal description of the study site was the center of the NW 1/4, SW 1/4, S.33, T.2N, R.41E of the Montana Principal Meridian.

Figure 4. Study site location, Colstrip, Montana.




## Topography

Resistance of geologic strata to erosion largely determines the topography of the Colstrip area (Skilbred 1979). The landscape is dominated by rolling prairies with alternating ridges, drainages, and sandstone bluffs. Most streams drain to the north and eventually flow into the Yellowstone River.

The study site was located on a north facing hilltop at an elevation of approximately 1036m above sea level. The study site was fairly level with convex slopes of 0 to 3 percent. The slopes gradually increased in steepness from south to north across the study site.

## Climate

Continental climatic conditions exist in the Colstrip area with cold winters and warm summers (Meyn et al. 1976). July is usually the warmest month, while January the coldest (Munshower and DePuit 1976). Colstrip's climate is semiarid with an average of 40.1 cm of precipitation annually (N.O.A.A. 1981). The majority of the precipitation comes in the form of rain during the months of April, May, and June.

Mean long term annual and monthly precipitation and temperature data were obtained from N.O.A.A. (1981). Monthly precipitation and temperature data for the 1982 growing season were obtained directly from the U.S. Weather Service reporting station in Colstrip. Table 4 lists the monthly averages and deviations from the long term averages for temperature and precipitation at Colstrip. During the study temperatures were below normal during April and May, while above normal during March, June, July, and August. Precipitation was below normal between the months of April and August, but above normal in March.

Table 4. Mean monthly temperature, precipitation and deviations from the long term norm, Colstrip, Montana, 1981-82.

| Month | Mean temperature °C | Deviation °C | Mean precipitation cm | Deviation cm |
|---|---|---|---|---|
| October | 7.2 | -2.0 | 3.8 | 1.2 |
| November | 5.6 | 5.9 | 1.3 | -0.4 |
| December | - | - | 2.0 | 0.4 |
| January | -11.1 | -5.0 | 2.5 | 1.1 |
| February | -3.9 | -0.9 | 0.5 | -0.9 |
| March | 2.2 | 2.1 | 5.6 | 3.7 |
| April | 5.0 | -2.1 | 3.3 | -1.4 |
| May | 10.6 | -1.4 | 4.1 | -2.2 |
| June | 17.2 | 0.1 | 4.8 | -3.6 |
| July | 23.3 | 1.4 | 2.6 | -0.4 |
| August | 24.4 | 3.2 | 2.9 | -0.6 |

## Vegetation

Rangeland in eastern Montana is generally classified as mixed grass prairie association (Payne 1973). The major subtype of this association in the Colstrip area is ponderosa pine savannah. The dominant species in this subtype are *Agropyron smithii*, *A. spicatum*, and *Bouteloua gracillis*. Ross and Hunter (1976) classified the climax vegetation of the Colstrip area as a complex of Silty and Clayey range sites. In addition the Forest-Grassland complex range site is also found in some locations surrounding Colstrip. Approximately 53 percent of the rangeland in Rosebud County is in good to excellent condition.

Prior to placement of cover soil on the study site, *Salsola kali* and other annual forbs were the dominant species. After placement of cover soil in late September 1981, no germination or plants were observed on the site for the remainder of the year.

## Geology

Veseth and Montagne (1980) described the geologic history of eastern Montana including the Colstrip area. Following the retreat of the last major Cretaceous sea, soft nonmarine sediments spread over the plains and basins of eastern Montana. During the early Tertiary period of the Paleocene epoch, creation of the Fort Union Formation occurred. The Tongue River member of the Fort Union Formation encompasses the Colstrip area. The Tongue River member is composed of soft interbedded light yellow to yellowish gray lenticular sandstones; gray claystones and shale; thin dark carbonaceous shales; coal seams; and clinker beds. Clinker beds were formed by burning shallow coal beds baking overlying sediments into reddish beds of various hardness. Clinkers often form resistant caps on buttes and ridges of the Colstrip area.

## Soils

On nearly level to moderately steep hills and plains, a mixture of Camborthids and Torriorthents are recognized (Schafer et al. 1979).

A mine soil profile typical of the study site was described according to Soil Taxonomy (Soil Survey Staff 1975), with modifications for mine soils suggested by Schafer (1979a). The soil profile description is listed in Table 22 of Appendix A. The soils of the study site were classified as Typic Ustorthents. Using unofficial soil series names from Schafer (1979a), the study site was placed into the Cow Creek Series. Evidence from the soil profile suggested that original topsoil and subsoil from the one lift cover-soil stockpiling operation did not thoroughly mix. Pockets of strongly contrasting dark material, possibly remanent of former A horizons were found scattered throughout lighter colored material which may have been the original subsoil. It is possible the nutrient status of these two materials differ, and may cause variation in vegetational growth within plots over the study site.

Using criteria developed by Schafer (1979b), the study site was classified as Land Capability Class IV. This class is suitable for cultivated pasture and rangeland, but not suitable for row crops. The major limitation of the study site was due to lack of topsoil as defined as material from the original A horizon. Topsoil was not segregated from subsoil during the stockpiling operation. At least 15 cm of original topsoil would have been needed on top of the coversoil material in order for the site to have qualified as Class III.

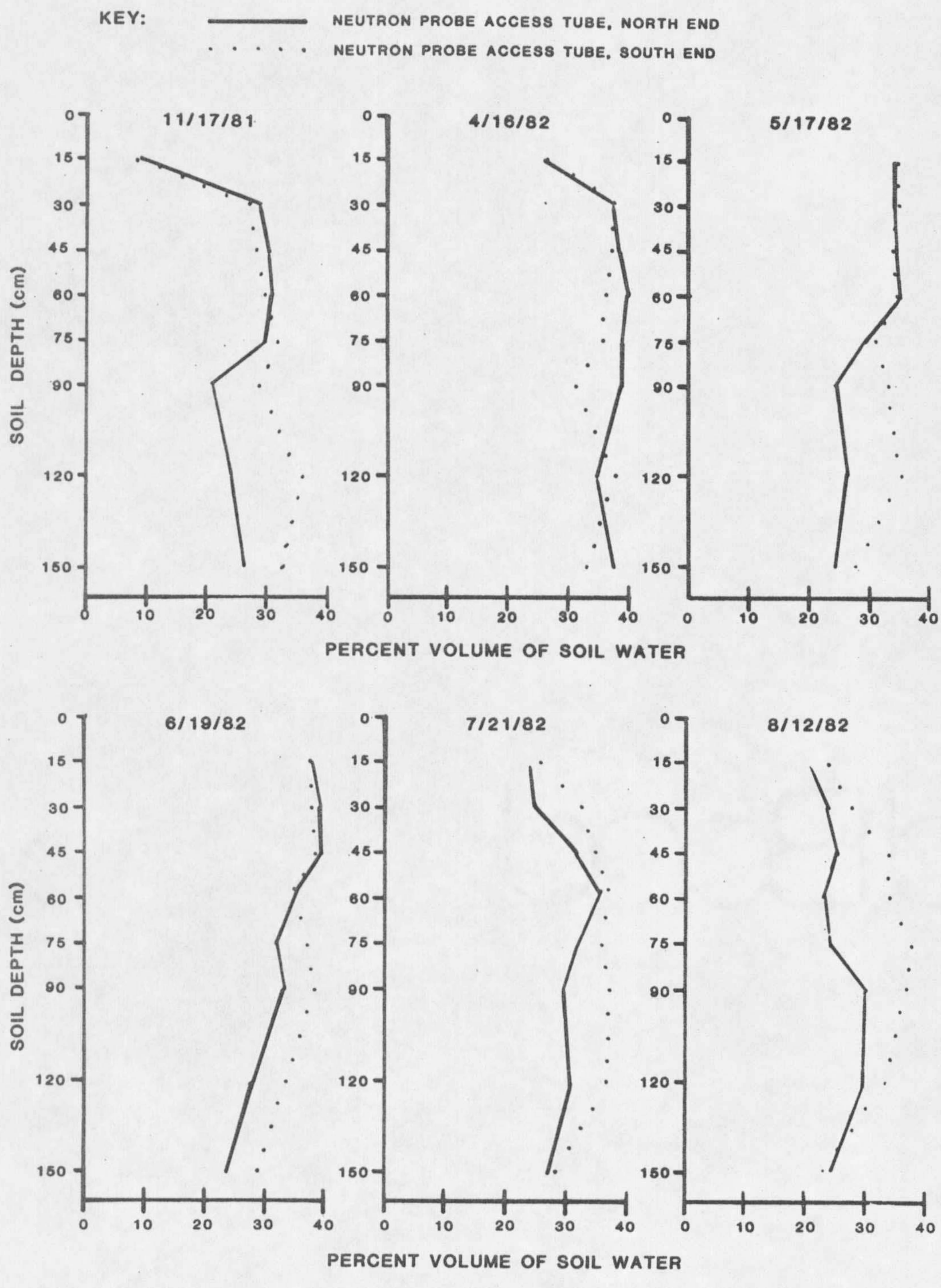
Baseline data for soils on the study site is listed in Table 5 by block and depth interval. Generally little variation in soil properties occurred for each depth interval by block. One exception was the sodium absorption ratio for the 0-30 cm interval in Block 1 and the 30-60 cm interval in Block 3. The SAR values were higher than those found for other blocks and depth intervals, but not high enough to interfer with plant growth and development.

Volumetric soil moisture content is graphed in Figure 5. In November 1981 and the following April, soil moisture content of the upper soil profile was generally low. By May and June soil moisture

Table 5. Baseline soils data of the study site, October, 1982.

| | Soil depth (cm) by block | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Block 1 | | | Block 2 | | | Block 3 | | |
| Soil parameter | 0-30 | 30-60 | 60-120 | 0-30 | 30-60 | 60-120 | 0-30 | 30-60 | 60-120 |
| $NO_3$-N (ppm) | 8.2 | 13.0 | 5.5 | 7.4 | 9.5 | 5.0 | 8.0 | 8.6 | 4.7 |
| Total N (%) | .056 | .059 | .047 | .052 | .051 | .038 | .055 | .046 | .041 |
| Organic matter (%) | 0.9 | 0.7 | 0.9 | 0.9 | 1.6 | 1.2 | 0.8 | 0.9 | 1.2 |
| C/N | 9.3 | 6.9 | 11.1 | 10.0 | 18.2 | 18.3 | 8.4 | 11.3 | 17.0 |
| Extractable P (ppm) | 2.2 | 1.4 | 0.6 | 2.0 | 2.0 | 1.2 | 2.8 | 1.7 | 1.2 |
| Extractable K (ppm) | 118.0 | 121.0 | 87.0 | 116.0 | 122.0 | 98.0 | 108.0 | 108.0 | 88.0 |
| Exchangeable Ca (meq/100g) | 20.82 | 24.16 | 17.19 | 28.87 | 24.88 | 19.31 | 30.52 | 22.09 | 11.07 |
| Exchangeable Mg (meq/100g) | 4.82 | 3.83 | 2.80 | 5.32 | 4.53 | 3.48 | 4.87 | 4.71 | 3.43 |
| Exchangeable Na (meq/100g) | 0.02 | 0.12 | 0.06 | 0.18 | 0.10 | 0.10 | 0.09 | 0.16 | 0.16 |
| Cation Exchange Capacity (meq/100g) | 11.5 | 10.2 | 8.0 | 11.1 | 11.0 | 8.6 | 10.3 | 9.8 | 7.2 |
| pH | 7.68 | 7.88 | 7.63 | 7.79 | 7.49 | 7.81 | 7.54 | 7.85 | 7.55 |
| Sodium absorption ratio | 3.2 | 0.92 | 0.87 | 1.08 | 0.91 | 1.22 | 0.98 | 2.27 | 0.84 |
| % sand | 43 | 43 | 49 | 44 | 48 | 46 | 46 | 44 | 46 |
| % clay | 23 | 23 | 18 | 23 | 23 | 23 | 23 | 23 | 20 |
| % silt | 34 | 34 | 33 | 33 | 29 | 31 | 31 | 33 | 34 |
| Texture class | loam | loam | loam | loam | loam | loam | loam | loam | loam |

Figure 5. Volumetric soil moisture content, 1981-82.



content near the surface had increased from precipitation events. As the summer progressed, soil moisture content of the study site decreased.

# RESULTS AND DISCUSSION

## Introduction

The objective of this study was to determine first year response of a native species mixture to 24 fertilization treatments on mine soils at Colstrip, MT. The treatments consisted of factorial combinations of N, P, and K. Vegetational response to the fertilization treatments was evaluated by measuring density, aerial biomass, canopy cover, and frequency for the various plant classes comprising the newly established plant community. In addition diversity, evenness, and richness were calculated for each fertilization treatment. Soil analyses were conducted on the study site at the end of the first growing season to determine how fertilization affected the nutrient status of the soil.

Results and Discussion are divided into sections by fertilizer element and related topics. The phosphorus, nitrogen, potassium, and nutrient interactions sections detail how fertilization affected the plant community and its components. In addition, these sections include results and discussion on post fertilization soil analyses. The adequacy of regression model section discusses the limitations of the regression equations.

Appendix B contains all the analysis of variance tables referred to in this study. Generally, experimental results are discussed in terms of plant classes. For the person interested in the results of a specific fertilization treatment on a particular species, Tables 30 to 33 of Appendix C contain this information listed by data parameter.

Phosphorus

This section discusses the effects of P fertilization by plant classes, plant community development, and residual effects on the soil.

Phosphorus fertilization affected the density, aerial biomass, and canopy cover response of several plant classes (Tables 23, 24, and 25; Appendix B). Regression analyses evaluated the influence of P on the plant classes signficantly affected by fertilization. Level of P fertilization was defined as the independent variable while vegetational response as the dependent variable. Both linear and quadratic models were evaluated. Significance was defined as the rejection of the null hypothesis (all slope coefficients equal to zero) with a probability greater than 95 percent. The lack of fit test (LOF) described by Neter and Wasserman (1974) tested the appropriateness of regression models in which slope coefficients proved significant. Lack of fit tests the null hypothesis that the expected value of the dependent variable is equal to the regression model. Significance for the LOF test occurs with an acceptance of the null hypothesis at a probability greater than 95 percent. For regression models that proved non significant for the LOF test, alternative models were tested until an appropriate model was fitted.

Regression models for which slope coefficients and appropriateness proved significant are illustrated in Figures 6 to 15. The corresponding p values for the t test and coefficients of determination are also listed. On each of the regression illustrations, the dot represents the mean response for all combinations of N and K fertilization with a specific level of P for the plant class and data parameter being estimated. The verticle line drawn through each mean response represents the 95 percent confidence interval that contains the mean response, and is based on the eight combinations of N and K fertilization associated with a particular level of P.

<u>Cool Season Perennial Grasses</u>

Table 6 summarizes the data collected for cool season perennial grasses. Phosphorus fertilization did not significantly affect the data parameters tested for this plant class (Table 23, 24, and 25; Appendix B). Frequency also was unaffected by P fertilization (Table 33, Appendix C). Meyn et al. (1975) stated that evidence from Colstrip and the literature indicated fertilization has unpredictable effects on perennial grasses during the first growing season. This unpredictability in cool season grass response may be due to variation in factors such as precipitation, soil temperature, and site characteristics.

Cool season grasses may not have responded to P fertilization due to climatic conditions. During April and May 1982 average monthly temperatures were lower than the long term average for Colstrip (Table 4). Precipitation was also below normal for the months from April to August (Table 4). The lower temperatures and precipitation may have reduced growth rates of cool season perennial grasses. If different climatic conditions such as warmer temperatures and higher precipitation existed during the first season of growth, responses to fertilization may have occurred for cool season perennial grasses.

Table 6. Vegetational statistics of cool season perennial grasses by fertilization treatment, 1982.

| Fertilizer treatment | Density May plants/$m^2$ | Density July plants/$m^2$ | Aerial biomass kg/ha | Canopy cover % |
|---|---|---|---|---|
| N0 P168 K0 | 100.0 | 100.7 | 327.6 | 30.9 |
| N0 P168 K28 | 105.6 | 85.6 | 319.6 | 26.0 |
| N14 P168 K0 | 90.0 | 74.8 | 226.8 | 20.0 |
| N14 P168 K28 | 95.0 | 98.5 | 222.4 | 19.4 |
| N28 P168 K0 | 95.6 | 94.1 | 222.8 | 18.0 |
| N28 P168 K28 | 83.9 | 84.8 | 262.8 | 27.4 |
| N56 P168 K0 | 69.4 | 55.9 | 347.6 | 16.4 |
| N56 P168 K28 | 98.3 | 80.0 | 261.2 | 20.6 |
| N0 P112 K0 | 106.7 | 87.8 | 234.0 | 23.1 |
| N0 P112 K28 | 80.0 | 64.4 | 255.6 | 16.2 |
| N14 P112 K0 | 81.7 | 76.3 | 246.0 | 20.4 |
| N14 P112 K28 | 95.6 | 79.6 | 258.0 | 27.1 |
| N28 P112 K0 | 103.9 | 90.4 | 338.8 | 24.8 |
| N28 P112 K28 | 103.3 | 107.8 | 217.6 | 27.7 |
| N56 P112 K0 | 77.2 | 75.6 | 210.4 | 21.0 |
| N56 P112 K28 | 89.4 | 94.8 | 164.0 | 23.7 |
| N0 P0 K0 | 81.7 | 81.9 | 212.0 | 13.2 |
| N0 P0 K28 | 94.4 | 81.9 | 105.6 | 12.2 |
| N14 P0 K0 | 115.6 | 105.9 | 202.8 | 15.4 |
| N14 P0 K28 | 88.9 | 87.0 | 306.4 | 20.0 |
| N28 P0 K0 | 63.3 | 70.4 | 165.2 | 21.6 |
| N28 P0 K28 | 90.6 | 85.6 | 170.8 | 16.4 |
| N56 P0 K0 | 100.6 | 91.5 | 169.6 | 18.6 |
| N56 P0 K28 | 138.3 | 109.3 | 243.6 | 23.1 |

## Warm Season Grasses

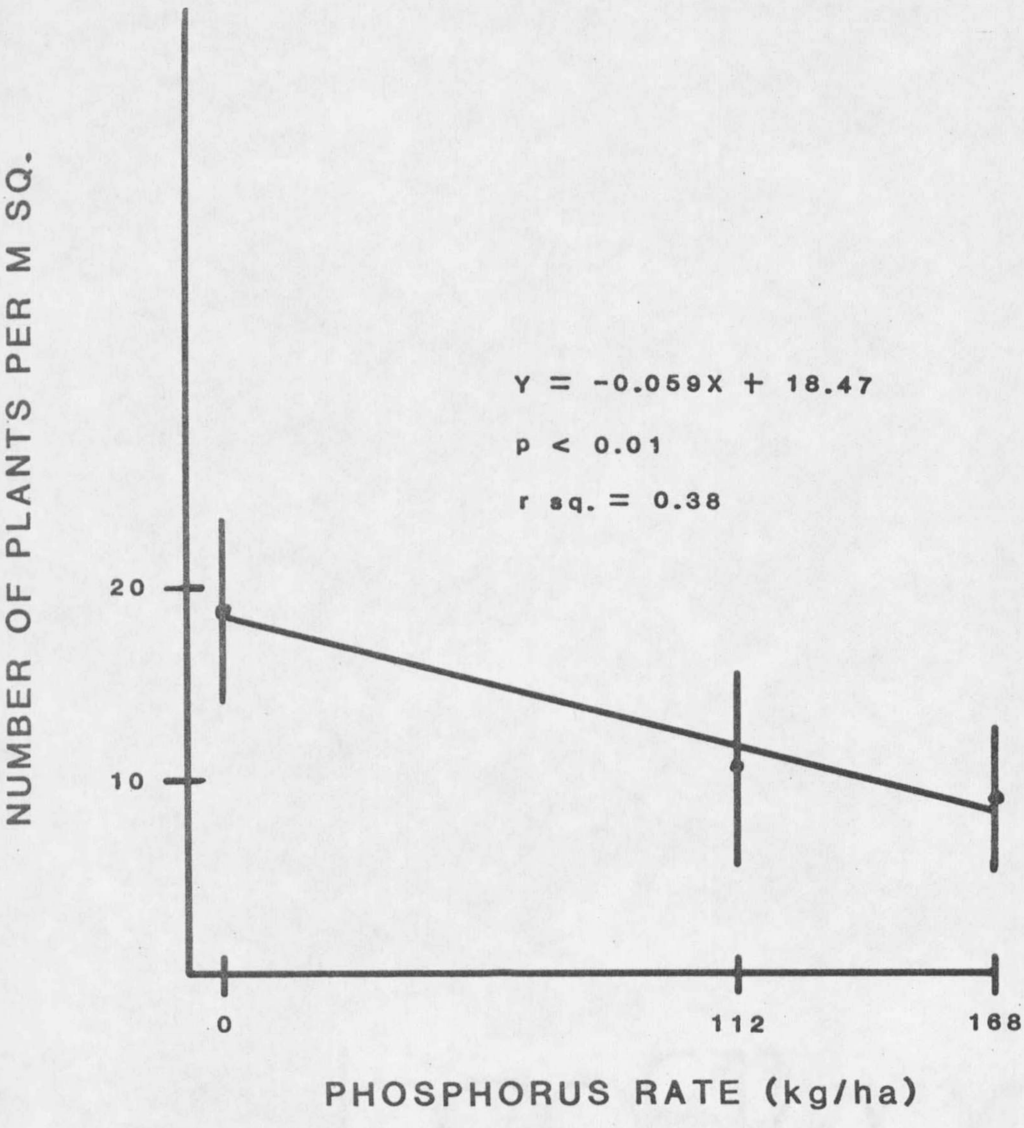
Table 7 sumarizes the data collected for warm season grasses. Phosphorus fertilization significantly affected the density, aerial biomass, and canopy cover of this plant class (Tables 23, 24, and 25; Appendix B).

During May, density of warm season grasses was zero, but by late June emergence occurred. A four factor ANOVA evaluated the effect P fertilization had on the July density data (Table 23, Appendix B). Phosphorus proved significant for the July density data and tended to decrease grass density as fertilization increased (Figure 6). Little information existed in the literature on how fertilization affects emergence of warm season grasses. Welch et al. (1962) reported fertilization of this plant class in Texas did not affect emergence.

Table 7. Vegetational statistics of warm season grasses by fertilization treatment, 1982.

| Fertilizer treatment | Density May plants/$m^2$ | Density July plants/$m^2$ | Aerial biomass kg/ha | Canopy cover % |
|---|---|---|---|---|
| N0 P168 K0 | 0.0 | 11.9 | 2.4 | 1.1 |
| N0 P168 K28 | 0.0 | 14.1 | 1.2 | 1.0 |
| N14 P168 K0 | 0.0 | 5.2 | 1.6 | 0.7 |
| N14 P168 K28 | 0.0 | 10.4 | 2.8 | 1.0 |
| N28 P168 K0 | 0.0 | 13.3 | 2.8 | 0.6 |
| N28 P168 K28 | 0.0 | 11.1 | 3.2 | 1.2 |
| N56 P168 K0 | 0.0 | 1.5 | 2.0 | 0.0 |
| N56 P168 K28 | 0.0 | 5.6 | 2.4 | 0.5 |
| N0 P112 K0 | 0.0 | 5.9 | 1.2 | 0.7 |
| N0 P112 K28 | 0.0 | 3.7 | 3.2 | 0.6 |
| N14 P112 K0 | 0.0 | 23.7 | 4.4 | 1.2 |
| N14 P112 K28 | 0.0 | 8.5 | 1.6 | 1.2 |
| N28 P112 K0 | 0.0 | 8.5 | 1.2 | 0.7 |
| N28 P112 K28 | 0.0 | 11.1 | 3.2 | 0.7 |
| N56 P112 K0 | 0.0 | 8.9 | 1.6 | 0.8 |
| N56 P112 K28 | 0.0 | 17.4 | 3.2 | 0.8 |
| N0 P0 K0 | 0.0 | 22.2 | 8.8 | 1.4 |
| N0 P0 K28 | 0.0 | 19.3 | 7.6 | 1.3 |
| N14 P0 K0 | 0.0 | 29.3 | 7.2 | 1.9 |
| N14 P0 K28 | 0.0 | 18.9 | 8.8 | 1.8 |
| N28 P0 K0 | 0.0 | 13.7 | 5.6 | 1.1 |
| N28 P0 K28 | 0.0 | 18.9 | 6.4 | 1.4 |
| N56 P0 K0 | 0.0 | 10.0 | 4.8 | 1.3 |
| N56 P0 K28 | 0.0 | 17.8 | 3.2 | 1.8 |

Figure 6. Mean density of warm season grasses in response to P fertilization, July, 1982.



It should be noted at this point that P fertilization did not significantly affect the first growing season density of other plant classes analyzed in this study (Table 23, Appendix B). Other studies agreed with these results (Aldon 1978, DePuit et al. 1978, Holechek 1976).

Phosphorus fertilization tended to decrease the aerial biomass (Figure 7) and canopy cover (Figure 8) of warm season grasses. Several rangeland studies reported similar results (Johnston et al. 1967, Wight and Black 1979).

Only P fertilization had an effect on the frequency of warm season grasses (Table 33, Appendix C). To better show this effect, frequency is listed in Table 8 by taking the mean of all combinations of N and K at a specific level of P for each plant species. Frequency of warm season grasses tended to decrease with increased P fertilization.

Identification of warm season grasses by species was not possible until mid August due to the lack of development in individual plants. As a result, green bristle grass (Setaria viridis), a warm season annual, was counted as a perennial. In mid August, green bristle grass composed only a small portion of the warm season grass population. Other species on the study site included sideoats grama (Bouteloua curtipendula), blue grama (B. gracilis), and prairie sandreed (Calamovilfa longifolia).

Increased competition from other plant classes as the result of P fertilization may have caused the adverse effects on warm season grasses. Emergence of warm season grasses did not occur until late