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THE UNIVERSITY OF ALBERTA

# REVEGETATING A PIPELINE RIGHT-OF-WAY ON A MONTANE GRASSLAND

by

Donald Wishart

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Master of Science

Department of Forest Science

EDMONTON, ALBERTA

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled REVEGETATING A PIPELINE RIGHT-OF-WAY ON A MONTANE GRASSLAND submitted by Donald Wishart in partial fulfilment of the requirements for the degree of Master of Science in Forest Science.

Kenneth O. Higginbotham

Supervisor

Date 18 May, 1983

## Abstract

The objectives of this research were to determine the potentials of different topdressings, fertilizer and seeding methods in revegetating a disturbed site in a harsh environment. The site was located alonn a pipeline right-of-way in a montane grassland in Jasper National Park, Alberta. A short growing season, low soil moisture regime, nutrient deficencies, high soil alkalinity, poor natural seed sources and overgrazing by native ungulates had combined to severely restrict natural secondary succession after disturbance.

Field experiments tested the effectiveness of three topdressing treatments (10 cm of acidic peat, 7.5 cm of alkaline loamy sand and no topdressing), two fertilizer treatments (785 kg/ha of ammonium-phosphate-sulfate versus no fertilizer), and four seeding method treatments (raking, packing, mulching and broadcasting seed). Greenhouse experiments were used to determine the effect of soil moisture and temperature on topdressing and fertilizer treatments. Three native shrub, three legume and ten grass species were used in the field experiments, while five grass species were used in the greenhouse experiments. Ground cover was measured periodically in the second growing season after seeding in field experiments. In greenhouse experiments, plant heights and weights were recorded.

Topdressing with loamy sand produced poorer results than no topdressing, while topdressing with peat was not

statistically different from not topdressing. Both peat and loamy sand topdressing materials were found to be less fertile than the original soils. Above-average precipitation likely overcame any beneficial effects peat may have produced on soil moisture. Peat also caused a delay in plant development in the Spring.

Fertilizing significantly improved growth. Increases in ground cover averaged 6.8 percent and persisted throughout the second growing season, although soil tests indicated that the applied nutrients were almost completely unavailable.

Method of seeding did not significantly affect ground cover. Raking produced slightly greater cover than other methods on fertilized plots. Mulching was the poorest method.

Fertilization and packing the seed into a non-topdressed seedbed produced the greatest average ground cover, 39.37 percent. The combination of the most successful single treatments, no topdressing, fertilizing and raking, produced only 37.08 percent ground cover, which indicated the hazards of selecting a combination of treatments on the basis of results of single factor analyses. Simply broadcasting seed onto an unamended, rototilled surface produced ground cover of 35.74 percent.

Germination tests were conducted on each of the species used in the field experiments. Small-sized grass seeds and shrub seeds had poor germinability.

By the end of the second growing season, nine grass species and three legumes had become established and produced an average of 30.3 percent ground cover. Those species that were successful in the field experiments had good germinability. The species that failed to establish had poor germinability and the viability of the seed may have been more important in the establishment of species than site characteristics.

If weather conditions are suitable, seedbed tillage and broadcast seeding alone can be sufficient to establish a productive, native plant community in a harsh mountain environment.

# Preface

The field plot studies, which were a major component of the research, were established as part of an Environmental Impact Assessment for a proposed pipeline through Jasper National Park, Alberta. Kitimat Pipelines Limited, the pipeline proponent, financed the establishment and initial analyses. In mid-July 1977, Kitimat suspended their pipeline proposal as well as their environmental studies. From that date to present, Parks Canada has provided project funding.

The field plot studies were administered and coordinated by Dr. H. Vaartnou, President, Vaartnou and Sons Enterprises Limited for the two years considered in this research report. Parks Canada has administered and monitored the plots from 1979 to the present.

The author of this report managed the field studies in 1977 and 1978 as an employee of Vaartnou and Sons Enterprises Limited. This responsibility included site slection, plot layout and establishment, and plant monitoring. All other studies presented in this research report, including greenhouse experiments and analyses of field plot soils, were initated and funded by the author.

## Acknowledgments

The author wishes to acknowledge funding for the field plot studies provided by Kitmat Pipelines Limited and Parks Canada. The cooperation of Parks Canada in allowing access to the study site during restricted travel periods and permitting the removal of plant and soil materials for laboratory studies is also appreciated.

The author also acknowledges the cooperation offered by Trans Mountain Pipe Lines Limited in granting permission to conduct the field trials along their right-of-way.

A special acknowledgement is extended to Dr. H. Vaartnou who provided assistance, advice and encouragement throughout the field project without which this research would not have been possible.

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# 1. INTRODUCTION

Resource exploration and development in Western Canada encompasses a number of activities which alter or disturb the environment. Coincident with these activities has been a dramatic increase in the level of public awareness of the potential environmental damage which may result. In this respect, it has been suggested that the future of many resource development programs will be tied to the potential to mitigate environmental damage (Peterson and Etter 1970, Legislative Assembly of Alberta 1981).

One common impact which is generally considered undesirable is loss of vegetation. Areas lacking plant cover in otherwise continuously vegetated regions appear conspicious and aesthetically unappealing. The bare surfaces are much more susceptible to wind and water erosion than well-vegetated surfaces (Stallings 1957). Furthermore, areas lacking vegetation provide essentially no wildlife habitat.

The establishment of plant cover on disturbed sites is the first step in the development of a stable, self-sustaining plant-soil system. Revegetation encourages the establishment of a plant-nutrient cycle and can enhance the development of a soil medium with more productive physical, chemical and biological characteristics. In this manner, revegetation can accelerate the restoration of the disturbed land to its original condition.

Under favourable environmental conditions, the loss of plant cover as a result of development activities can be of short duration and can often be mitigated simply by natural succession. Conversely, in harsh enviornments, plant cover can be lost for several decades after disturbances. Walquist *et al.* (1975) stated that natural re-establishment of perennial plants on harsh sites is episodic. That is, those conditions which would lead to establishment of vegetation (above average precipitation, less winds, abundant seed crops, etc.) may occur only rarely. Therefore, it is important to develop techniques which will create suitable conditions for plant establishment and accelerate revegetation in these harsh environments.

One obvious method of overcoming any undesirable characteristics of the soil medium is to topdress the site with a more suitable material. In many areas of the world, experience and research have shown that topdressing can be the key to establishing desired plant cover (Tresler 1974, Curry 1975, Macyk 1977, McKell 1978). Schumacher *et al.* (1977) stated that in Alberta:

> "There is irrefutable evidence that short-term growth is dramatically improved by the selection and placement of more favourable growth media at the surface."

Studies at the North Dakota Agriculture Experiment Station (1975) indicated that a topdressing as thin as 5 cm can produce benefits of enhanced plant survival and growth. Furthermore, Howard and Samuel (1979) and Fedkenheuer and

Heacock (1979) concluded that topdressing materials can also act as a potential seed source for revegetation.

Fertilization is a proven method of restoring fertility in nutrient-poor sites. Fertilizers release nutrients as they pass into solution. Vogel (1973) found that revegetation was completely unsuccessful on coal mine spoils unless fertilizers were added. He concluded that available nutrients have to be at or near the surface to be accessible to juvenile plants. Bethlahmy (1960) found similar results with his revegetation trials on logging roads in coastal British Columbia. Curry (1975) concluded that the use of fertilizer to accelerate soil-plant succession on severely disturbed sites may be the only practical method for securing effective ground cover.

The success of revegetation efforts can be greatly influenced by the method of seeding. Walquist *et al.* (1975) found that the method of seeding was a critically important factor in seedling establishment on mined, arid grasslands. DePuit and Coenenberg (1979) also found significant differences between seeding methods in grassland revegetation experiments in a semiarid region of Montana and concluded that much more information is needed to determine suitable seeding methods, particularly for native species.

The integrity of the natural environment can be maintained through revegetation with native plant materials. Furthermore, the potential for creating weed problems commonly associated with the use of introduced species can be reduced wherever native plants are sown. However, there is little information regarding responses of native plant species to various revegetation techniques. In order to successfully use native plant species in revegetation programs, it is important to improve this information base.

Dick and Thirgood (1975) noted that effective revegetation can be best achieved by a combination of techniques. However, there has been a tendency to test and use few techniques in combination. By properly preparing the seedbed (e.g., topdressing), adequately fertilizing the site, selecting suitable plant materials and seeding according to the best proven methods, it is likely that revegetation success can be improved. Therefore, there is a need to test the combined effect of various revegetation techniques.

The purpose of this study was to provide more precise information on the effectiveness of topdressing, fertilizing and seeding methods in revegetating a harsh environment. A further objective was to improve the information base regarding the effect of these techniques on various native plant species. The research included a review of literature pertaining to each revegetation technique. A detailed description and analysis of relevant site factors also was conducted. Field studies were used to assess the effects of different techniques for establishment of plant cover. A greenhouse experiment was conducted to determine the effects of soil moisture and temperature on topdressing and fertilizer treatments on plant growth. Furthermore, germination tests and soil analyses were conducted to enhance the information base available to interpret the results of the field and greenhouse experiments. While the research generally was concerned with establishment of vegetation, the field trials were designed to be monitored for a number of years beyond those considered in this text and implications for long term success are discussed.

## 1.1 Problem Statements and Hypotheses

A review of relevant literature indicated that the use of topdressings, fertilizer, native plant species and/or various seeding methods could potentially enhance revegetation success on a harsh site. Breuninger and Thompson (1979) stated that the success of revegetation efforts should be measured in terms of percent ground cover. However, Peterson and Etter (1970) and Brown and Johnston (1978) considered the ability of the disturbed site to produce plant biomass also to be an important determinant of revegetation success.

In order to determine the potential of each technique to achieve increased cover, it was necessary to conduct studies to answer the following problem statement:

> Will the type of topdressing, the application of fertilizer and/or the method of seeding affect percent ground cover and will the effects of these treatments vary among the native plant species used?

Because it was desirable to monitor plant response throughout the growing season, it also was necessary to determine the effect that the time of year had on ground cover. This led to the following problem statement:

> Will percent ground cover change during the growing

season?

The use of topdressings and fertilizer also could increase plant biomass. In order to test this theory, experiments were conducted in order to determine:

> Will the type of topdressing and/or the application of fertilizer affect the weight or height of plants and will the effects of these treatments vary among the native plant species used?

From the problem statements, the following formal hypotheses were developed:

1. Season

   Percent ground cover does not change during the growing season.

2. Topdressing

   The type of topdressing does not affect percent ground cover, weight or height yield, and the effect does not vary among plant species.

3. Fertilizer

   The application of fertilizer does not affect percent ground cover, weight or height yield and the effect does not vary among plant species.

4. Seeding Method

   The type of seeding method does not affect percent ground cover and the effect does not vary among plant species.

5. Interactions

There are no interactions among the type of topdressing, addition of fertilizer and/or seeding methods, and their effect on percent ground cover does not vary among plant species.

There are no interactions among type of topdressing, addition of fertilizer and/or seeding methods, and their effect on plant height or weight does not vary among plant species.

## 1.2 Definitions

A number of definitions are required to qualify terms used in this text. Syncrude Canada Ltd. (1975) has defined four terms commonly used synonymously:

> "reclamation..... returning a disturbed site to a condition where the original organisms or similar organisms can inhabit the site.
>
> rehabilitation..... the land is returned to a stable ecological state according to a land use plan that does not contribute to further environmental deterioration.
>
> restoration..... the site conditions, including topography, will be returned to essentially the same state as they were prior to the disturbance.
>
> revegetation..... a provision of vegetative cover on a disturbed site."

In this report, no studies were made to determine the status of soil microorganisms or other fauna that periodically inhabit the site. Consequently, one of the major factors in determining reclamation success was not assessed. Land use planning for the site was also not considered as part of this research. These plans are an integral part of rehabilitation procedures. Furthermore, no attempts were made to restore site factors such as topography to their original condition. Therefore, this report is confined to the study of revegetation of a disturbed site.

The success of revegetation trials was measured in terms of percent ground cover, defined by Takyi and Russell

(1980) as:

> "the percent of ground area covered by a perpendicular projection of all above ground, living-plant parts."

A number of definitions also are required to qualify techniques used in revegetation:

topdressing -- the application of materials to a site to simulate topsoil development and improve seedbed characteristics.

fertilizing -- the application of commercially manufactured, inorganic plant nutrients to a site.

seeding methods -- any method of applying seed to a site including those that alter the seedbed to enhance seed germination and/or protect against erosion (i.e., broadcasting, raking seed into seedbed, packing seed into the seedbed, or hydromulching seed).

peat -- unconsolidated soil material consisting of largely undecomposed or only slightly decomposed, organic matter (Agriculture Canada 1976).

## 1.3 Site Selection and Location

In order to meet the study objectives, it was necessary to select a site that was difficult to revegetate. Selner (1973) identified high elevations and southern and western exposures as areas where revegetation is difficult after disturbance and that are, therefore, susceptible to long term environmental impacts. Walker *et al.* (1977) found that revegetation of disturbed grasslands in Alberta's Rocky Mountains was difficult and slow due to a lack of seed source and infertile soils. Martens and Nicholson (1976) inventoried numerous disturbed sites in Alberta and British Columbia's Rocky Mountains and found that the overall coarse-texture of mountain soils and associated low moisture retention capability limited revegetation potential. Other studies indicated that inherent instability and slow rates of formation of most mountain soils are limiting factors (Curry 1975, Dick and Thirgood 1975). Alberta Land Conservation and Reclamation Council (1980) found that windy and cold climatic factors also limit revegetation in mountain and foothill regions. Collectively, these studies indicated that environmental conditions in mountain grasslands are harsh and that revegetation can be expected to be difficult.

In order to select a site that had proven to be difficult to revegetate, a study of past development sites in mountain grasslands was conducted. An area in Jasper National Park where a pipeline was constructed in 1952 was examined. No attempt had been made to conserve topsoil during construction or to reclaim the right-of-way to a state similar to that which existed prior to disturbance. In the ensuing 25 years, many sites along the right-of-way remained void of vegetation. One denuded site was selected on the basis of three criteria which were considered critical to the field studies:

1. There must be distinctly less plant ground cover on the pipeline right-of-way than on adjacent, undisturbed land,
2. The site must be generally level so that topographic position could not be considered significant, and
3. The site must be accessible by road to allow transportation of large quantities of experimental materials.

The site was located off Celestine Lake Road near Jasper Lake and is approximately 18 km by road from Highway 16 (Figure 1). The legal site description is NW-27-47-1-W of 6 at 118°04′ west longitude and 53°05′ north latitude. As a result of frequent, strong winds, the site is known locally as Windy Point.

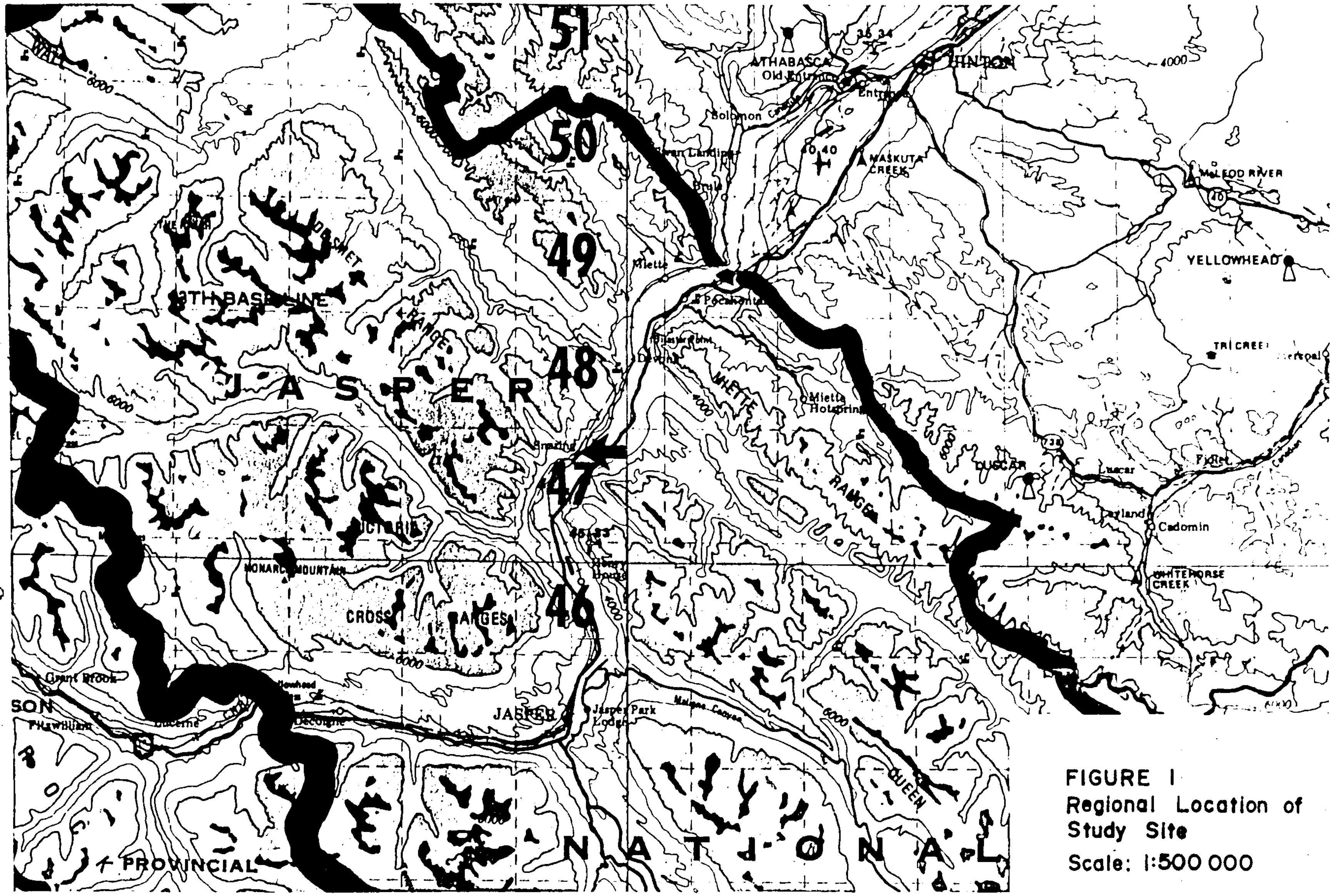


FIGURE I
Regional Location of
Study Site
Scale: 1:500 000

# 2. SITE DESCRIPTION

To date, three ecological zones have been recognized in Jasper National Park: montane, subalpine and alpine (Wells *et al.* 1978). They are separated primarily by vegetative physiognomy that, by inference, reflects macroclimatic complexes of temperature and moisture regimes associated with vertical zonation, slope and aspect. The ecological zone on which the study site was located has been defined as montane (Stringer 1969, Hettinger 1975, Wells *et al.* 1978). The montane zone is the driest and lowest of the three zones.

Within the montane ecological zone there are four integrading vegetation types. The most mesic sites are occupied by *Picea glauca* (Moench.) Voss [1] and *Populus tremuloides* Michx. forests. The dry-mesic sites are occupied by *Psuedotsuga menziesii* (Mirb.) Franco forests. *Pinus contorta* Loudon var. *latifolia* Engelm. forests are pioneer dominants on burned areas within the mesic and dry-mesic moisture classes. The most xeric sites in the montane zone are occupied by scrub-savanna and short-grass vegetation types (Stringer 1969). The study site was located on a xeric, montane short-grass vegetation type.

Areas of montane grasslands are not extensive in Alberta and, consequently, have significant interpretive and educational value. The montane grasslands are also important ungulate habitats (Flook 1964). All three national parks in

-----------------

[1]Taxonmic nomenclature follows Moss (1977)

Alberta's Rocky Mountains have areas of montane grasslands within their boundaries, and all of Alberta's major Rocky Mountain transportation corridors traverse montane grasslands. Undoubtedly, future park and/or transportation development will necessitate further disturbance of these grasslands. However, as discussed above, the grasslands are difficult to revegetate. Therefore, research designed to enhance revegetation success on these areas is necessary and warranted. Furthermore, the information derived from this research could be applicable to areas where environmental conditions are similar.

## 2.1 Climate

The macroclimate of the general region has been described as subhumid, continental with long, cold winters and moderate mild summers (Dumanski *et al.* 1972). However, as a result of topography characterized by relatively high local relief, there is subtle climatic zonation.

There are three meteorological stations in Jasper National Park that have more than five years of data. Jasper townsite, approximately 30 km south of the study site, is the closest station and has continuous data from before 1941 (Table 1). The townsite station is also located in a montane ecological zone at approximately the same elevation as the study site. The other two meteorological stations, Jasper East Gate and Jasper West Gate, are both located in cooler, more mesic subalpine ecological zones.

Frost may occur in all months of the year, however, the average frost-free period is 84 days, occurring between June 7 and August 31 (Environment Canada 1973). The effective growing season is defined as beginning with five consecutive days with mean daily temperature above 5.5°C and ending with five consecutive days with mean daily temperature below 5.5°C (Boughner 1964). At Jasper townsite the effective growing season is 157 days, generally occurring between May 1 and October 19 (Boughner 1964).

While no complete data are available, it appears that the montane grassland zone on which the study site was located receives less precipitation than the montane zone at

Table 1: Meteorological Averages for Jasper, Alberta (1941-70)

| | JAN | FEB | MAR | APRIL | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC | ANNUAL | SNOW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Preciptation (mm) | 30.2 | 24.1 | 14.7 | 22.6 | 34.8 | 49.8 | 47.5 | 48.0 | 34.8 | 30.2 | 32.5 | 33.0 | 402.2 | 1369 |
| No. of Days with Measurable Precipitation | 12 | 9 | 7 | 8 | 9 | 13 | 13 | 13 | 10 | 10 | 10 | 12 | 126 | 52 |
| Mean Temperature (°C) | -12.2 | -6.6 | -2.7 | 3.3 | 8.7 | 12.5 | 15.2 | 14.1 | 9.9 | 4.8 | -3.8 | -9.1 | 2.8 | |
| Mean Daily Maximum (°C) | -7.1 | -0.4 | 3.5 | 9.7 | 16 | 19.6 | 22.9 | 21.5 | 16.9 | 10.5 | 0.8 | -4.6 | 9.1 | |
| Mean Daily Minimum (°C) | -17.2 | -12.7 | -8.9 | -3.0 | 1.3 | 5.4 | 7.5 | 6.6 | 2.9 | -1.0 | -8.4 | -13.5 | -3.4 | |
| No. of Days with Frost (< 0°C) | 30 | 28 | 30 | 25 | 12 | 1 | 0 | 1 | 8 | 19 | 28 | 31 | 213 | |

Source: Environment Canada 1973

Jasper townsite. Hettinger (1975) calculated that the average total precipitation from June through August in 1970 and 1971 was 116 mm at his meteorological station located in a montane zone 0.5 km south of the study site. Comparatively, the montane zone at Jasper townsite averaged 173 mm, for the same periods.

At Jasper townsite approximately 68 percent of winds are from the south and southwest and the average annual velocity is 10 km/hr (Environment Canada 1973). These winds place much of Jasper National Park, including the study site, in the rainshadow of the Rocky Mountains. No wind direction or velocity data are available for the study site. However, the branches of the scattered *Picea glauca* trees adjacent to the study site are considerably shorter and sparser on the south sides of the trees. This branch distortion suggests that the winds at the study site are very strong, persistent and largely uni-directional from the south. The lower elevations of the Athabasca River Valley are subject to warm foehn winds (Dumanski *et al.* 1972). These winds cause marked snow ablation in winter, rapid snowmelt and runoff in spring and high rates of evapotranspiration in summer (Stringer 1969).

## 2.2 Physiography and Geology

Jasper's montane zone lies in the Rocky Mountain Area of the eastern systems of the Cordilleran Region (Baird 1963). In the area of the study site, the Rocky Mountains are defined by a series of broad folds cut by subparallel westward dipping thrust faults comprised of limestone and quartz of Devonian age (Kjearsgaard and Macyk 1978). The lower 450 m of the exposed Devonian section consist of dolomite, limestone, shale and siltstone (Baird 1963). These rocks are capped by more than 250 m of massive gray limestone of the Palliser Formation. The vast majority of exposed bedrock in the region is calcareous in nature (Wells *et al.* 1978).

The Athabasca River valley was one of the first areas in Alberta to be glaciated and one of the last to be deglaciated (Roed 1975). The region was glaciated during the Wisconsin glaciations. The specific ice advance in the area was named the Obed Glacier (Roed 1975). Ice advanced northeastward from the mountains along what is now the Athabasca River valley. There also have been several local alpine glaciers in the valley.

Jasper Lake, which lies immediately adjacent to the study site, is a remnant of meltwater that flooded the valley after the retreat of the main ice-sheets. The early postglacial lake covered the study site and was approximately 100 km long and 120 m above the present level of the lake (Baird 1963). The lake transported enormous quantities of loosened, locally-derived rock and rubble and left the study site and most of the valley walls surfaced with these unconsolidated glaciofluvial materials. Late postglacial and recent movement of these materials on the steep slopes above the study site, has resulted in the development of a colluvial blanket which presently overlies the glaciofluvial material in the area of the study site (Stringer 1969, Hettinger 1975). These materials are largely comprised of cobbles, pebbles and coarse sand (Wells *et al.* 1978, Kjearsgaard and Macyk 1978). Because they are predominantly derived from local bedrock, these unconsolidated materials are calcareous in nature (Baird 1963).

Postglacial sorting by wind has been an important factor affecting the surficial geology of the area. Dunes, blankets and veneers are common throughout Jasper's montane grasslands (Wells *et al.* 1978). The Windy Point area has been mantled with a thin veneer (about 20 cm thick) of aeolian material (loess), which is believed to be derived from the limestone of the Palliser Formation bedrock (Kjearsgaard and Macyk 1978). The loess is silty to fine sand in texture and is highly calcareous (Dumanski *et al.* 1972).

In the Athabasca River valley, these montane grasslands generally occur at elevations between 1000 and 1600 m. However, on steep slopes they can extend to 1800 m (Hettinger 1975). These grasslands generally occupy south-facing slopes. The study site was located at 1035 m elevation with a very gentle (2-5%) slope forming a west-southwest aspect (Figure 2).

## 2.3 Soils

The soils of Alberta's Cordilleran Region are characterized by weak development (Kjearsgaard and Macyk 1978). Stringer (1969), Dumanski *et al.* (1972), Hettinger (1975) and Wells *et al.* (1978) classified the soils in the vicinity of the study site as Orthic and Cumulic Regosols as defined by the Canada Soil Survey Committee, Subcommittee on Soil Classification (1978). Orthic Regosols occur where loess deposition is relatively continuous. Cumulic Regosols are characteristic of sites where deposition is periodic, creating a layered pattern of buried Ah horizons (Kjearsgaard and Macyk 1978).

Stringer (1969) found the soils at the study site to be sandy loam textured with about 9 percent gravel-sized material to a 90 cm depth. The surficial 10 cm was generally gravel-free; the proportion of gravel increased with depth. The depth of topsoil (Ah horizon) averaged 3 to 5 cm (Stringer 1969, Hettinger 1975).

Wells *et al.* (1978) described the soils in the area of the study site as having low organic contents and being rapidly drained. Moisture deficiencies related to climate are compounded by the rapid drainage. Stringer (1969) estimated that in normal summers, the montane grassland at

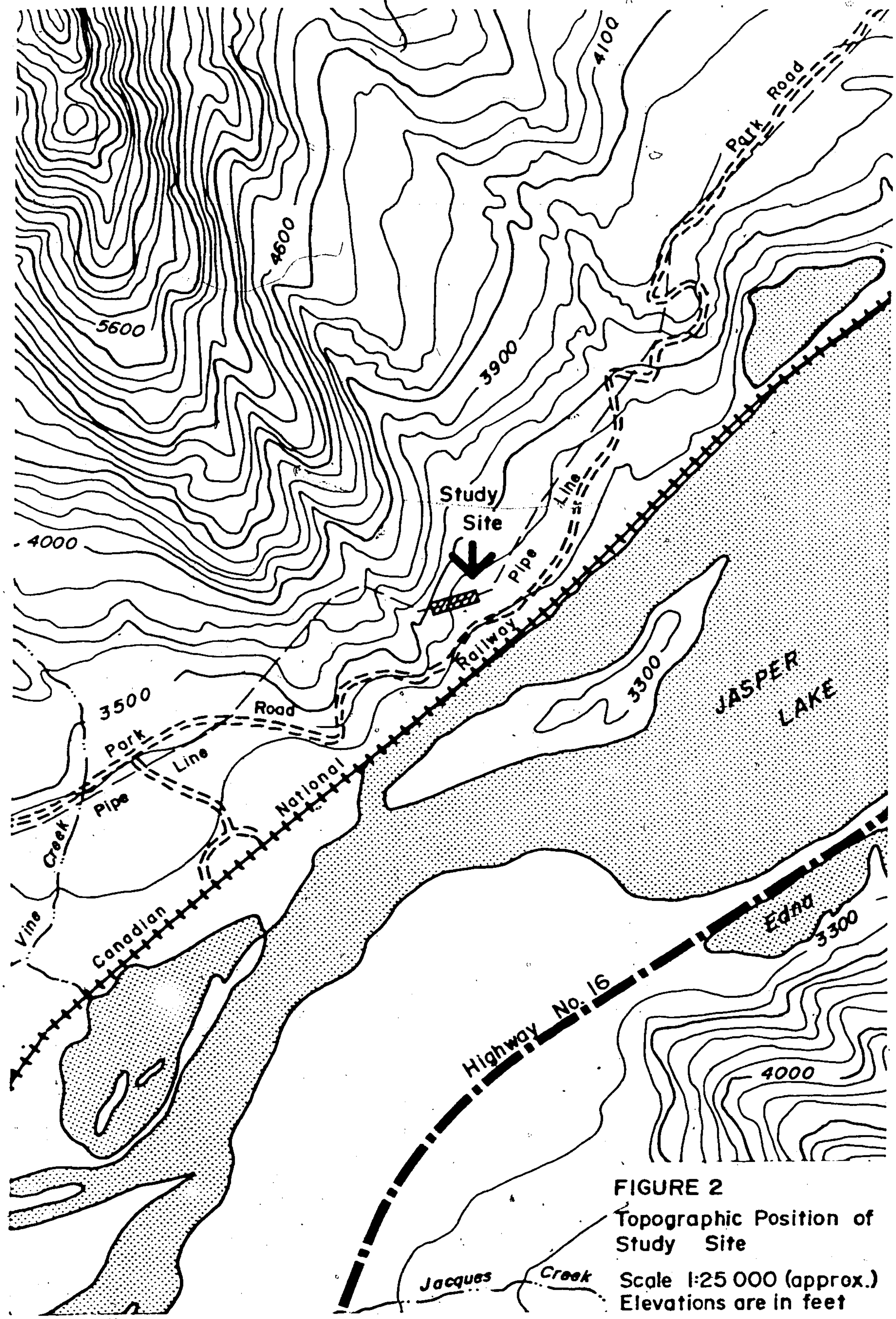


FIGURE 2
Topographic Position of Study Site
Scale 1:25 000 (approx.)
Elevations are in feet

Windy Point has a soil moisture deficit from late June or early July until late October, totalling approximately 110 mm. Hettinger (1975) found similar results and estimated that soil water potential is below -15 bars (nominal permanent wilting point) for at least one-third of the potential growing season. Since the soils are only slightly saline, the effect of soil salts on moisture availability was not significant.

These coarse-textured, organically-poor soils generally lack the cohesion necessary to prevent soil movement (Stallings 1957). Dumanski *et al.* (1972) rated nearby soils with characteristics similar to those at the study site as having high soil erosion potential. This high erosion potential rating was relative to other soils in a region where they considered essentially all soils to be highly erodible.

Stringer (1969) found 3 ppm of available nitrogen and 1 ppm of available phosphorus in surficial soils collected at the study site. Potassium concentrations were 68 ppm and were not considered to be a limiting factor to plant growth. Hettinger (1975) found 2 ppm of available nitrogen and no available phosphorous in soil samples taken from a montane grassland site approximately 1 km south of the study site. He also found potassium levels to be in excess of 60 ppm.

Both Stringer (1 and Hettinger (1975) found soils in the study area to be moderately to strongly alkaline (pH 8.0 to 8.8) and to have high levels of free lime. The alkaline soil conditions at the study site can induce deficiencies of several macro- and micro-nutrients. At high pH levels, nutrients such as phosphorus, iron, manganese, copper, zinc, cobalt and boron form chemcial compounds with low solubilities (Brady 1974) (Figure 3). In these forms, the nutrients are unavailable for plant uptake and, thus, deficiencies are induced. While the effect of free lime in the soil is predominantly the creation of alkaline conditions, the presence of high concentrations of free lime has been found to hinder uptake and metabolism of even relatively soluble forms of phosphorous and potassium (Tisdale and Nelson 1975). Furthermore, zinc can be adsorbed by the lime and become unavailable for plant use (Tisdale and Nelson 1975).

## 2.4 Vegetation

As the name implies, the montane grassland has a very open physiognomy. Ground cover is variable and bare ground is not uncommon (Stringer 1969). Stringer (1969) estimated that mean plant cover in the areas adjacent to the study site was approximately 80 percent with stunted trees and shrubs contributing 5 to 10 percent of the cover.

Just under 70 species have been identified on grasslands in the vicinity of the study site (Stringer 1969, Hettinger 1975, Wells *et al.* 1978). The dominant species identified by Stringer (1969) were *Koeleria cristata*[2],

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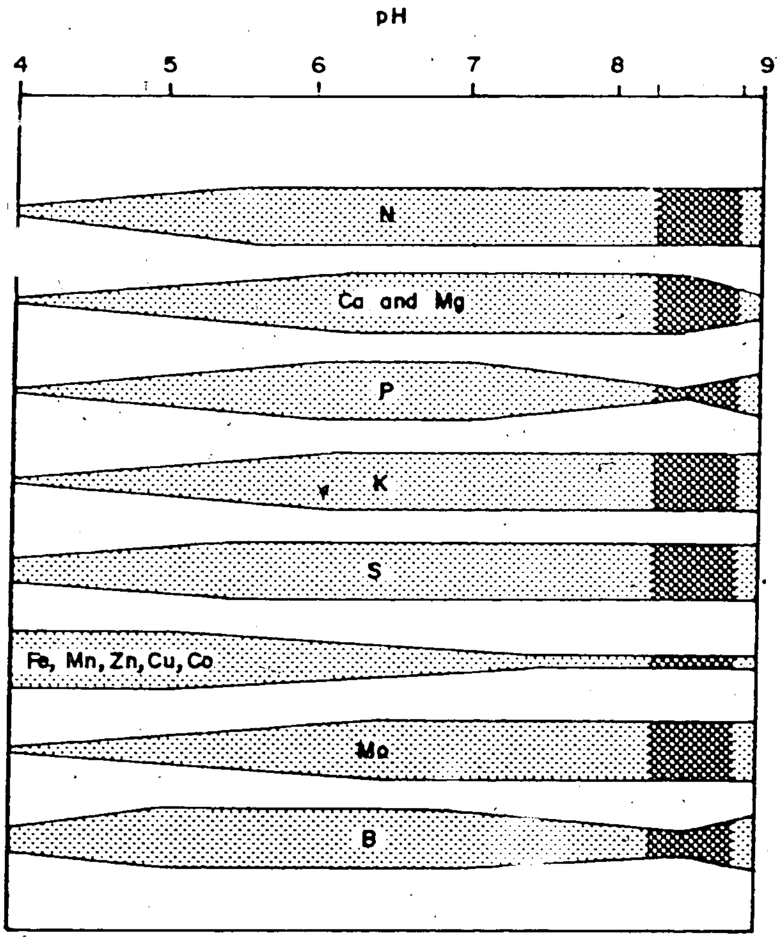
[2] Taxonomic authorities appear in Appendix A.

FIGURE 3: **Relationship Between pH and Nutrient Availability**

(From Brady 1974)




The wide portion of the bands indicates the zone of most ready availability of nutrients. The darker portion of the bands indicates the pH of the study site.

*Calamagrostis montanensis*, *Antennaria nitida/rosea*[3], *Artemisia frigida* and *Astragalus striatus*. Hettinger (1975) found *Arctostaphylos uva-ursi*, *Juniperus communis*, *Rosa acicularis*, *Calamagrostis purpurascens*, *Galium boreale* and *Artemisia frigida* the most common species. Wells *et al.* (1978) listed *Koeleria cristata*, *Antennaria nitida*, *Linum lewisii*, *Carex eleocharis* and *Artemisia frigida* among the most common species in the area. Many species were common to all three surveys. A complete list of species identified in the surveys is provided in Appendix A.

The results of the vegetation surveys suggest there is considerable diversity in the grassland and that the abundance of a given species varies significantly with minor variations in site. However, the general physiognomy and species present are relatively constant. Most of the species identified are drought tolerant bunch-grasses, which are increasers under heavy grazing (Stringer 1969). Research conducted on these montane grasslands indicated that biomass production is low (Stringer 1969). Furthermore, Walker *et al.* (1977) found that native, Rocky Mountain grasses produced low quantities of seed and that the viability of the seed was also inherently low.

The montane grasslands are believed to have developed largely in response to prevailing dry environments (Krajina 1965, Hettinger 1975). Grassland life forms can possess the ability to aestivate as soils dry beyond the permanent

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[3] Stringer was unable to distinguish between the two species

wilting point. Tree seedlings generally are unable to aestivate and consequently, forests are excluded from sites where soil water deficiencies are prolonged (Daubenmire 1943).

Two other factors have been suggested as being important to the development and maintenance of the montane grassland. Hettinger (1975) found a positive correlation between presence of free lime and herb and low shrub cover (edaphic climax). The strongly calcareous nature of the soil may prove toxic to coniferous seedlings, thereby restricting plant succession to grassland species, which are more tolerant of such conditions (Dumanski *et al.* 1972, Kjearsgaard and Macyk 1978). However, Stringer (1969) believed that forest encroachment is restricted on the grassland as a result of the combined effects of trampling, browsing and grazing by native ungulates (secondary zootic climax).

All these hypotheses suggest that the montane grassland represents a climax stage of succession. However, most grassland - forest interfaces in Alberta are believed to occupy a seral stage of succession that is naturally maintained by fire (Moss 1952). Fire has been suppressed since the inception of Jasper National Park in the early 1900's, yet there is no evidence of significant encroachment by later successional species. Therefore, it appears that the montane grassland is a climax stage of succession.

It is difficult to define the degree of relationship of Jasper's montane grassland to other plant communities due to a lack of quantitative data for most community descriptions. However, many of the species included in all three surveys mentioned are widely distributed on xeric and disturbed grasslands throughout northwestern North America. For example, *Juniperus horizontalis*, *Rosa acicularis*, *Potentilla fruticosa*, *Agropyron trachycaulum*, *Elymus innovatus*, *Bromus pumpellianus*, *Poa pratensis* and *Koeleria cristata* all have natural distributions covering much of the western part of continent (Scoggan 1979). *Koeleria cristata*, *Agropyron trachycaulum*, *Stipa* spp. and *Bromus* spp. are common in most low elevation grasslands in the Rocky Mountains and in the interior of southern British Columbia (Stringer 1969). The montane grasslands of Jasper National Park also have botanical affinities to the *Juniperus communis* - *Arctostaphylos uva-ursi* communities of the southwestern Yukon (Douglas 1974). They are also similar to the heavily grazed *Festuca* - *Symphoricarpos* association of eastern British Columbia (McLean and Holland 1958), the xeric grasslands of the Peace River area (Moss 1952) and to the stabilized dune associations of Saskatchewan (Hulett *et al.* 1966). The sagebrush ecological zones of northern Idaho (Daubenmire 1956), Wyoming (Despain 1973) and west-central Colorado (Langenheim 1962) have similar site factors and many of the same plant genera and species as those found in Jasper's montane grassland. The montane grasslands also have affinities to Coupland's (1961) Fescue Prairie and Palouse Prairie Associations of the North American Great Plains.

## 2.5 Grazing History

Five grazing animals are known to utilize Jasper's montane grasslands (Flook 1964). These are bighorn sheep (*Ovis canadensis* Shaw), elk (*Cervis canadensis* Bailey), mule deer (*Odocoileus hemionus* Rafinesque), moose (*Alces alces* Peterson) and horse (*Equius caballos* L.). Populations of sheep and elk are large, and elk have been harvested in most years since 1940 in order to reduce their populations (Stringer 1969). Deer and moose populations are much smaller. Horses are kept for park use only and their numbers and distribution are carefully controlled.

Sheep and elk utilize the montane grasslands all year (Flook 1964). Sheep mainly graze on grasses in the winter and forbs in the summer. Elk graze on grasses year round but will use forbs and woody shrubs to a minor extent. The grasslands are critical winter ranges for both sheep and elk since shallow snow cover allows access to ground vegetation. The montane grasslands are not as important to deer and moose, since both are primarily browsing animals and generally occur on the grasslands only at the edge of the forest. However, both species have been known to forage on the grasslands when browse in the forest is depleted (Stringer 1969). Placing restrictions on grazing patterns or distributions of native animals in the park is considered undesirable (Parks Canada 1970).

# 3. LITERATURE REVIEW

In order to establish plant cover at the study site, some or all of the conditions that may limit natural revegetation had to be ameliorated. The use of topdressings, fertilizer, various seeding methods and native plant materials appeared to have potential to accomplish this objective. A review of relevant literature regarding each technique follows.

## 3.1 Topdressings

Peterson and Etter (1970) pointed out that in mountainous regions there is often insufficient surface material available for use as a topdressing. As well, partial stripping of undisturbed soils within the park is not considered conducive to intensive recreational environments. Therefore, indigenous soils were not considered to be a practical source of topdressing materials. It was necessary to examine the potential of materials from outside the park boundaries. Two radically different potential topdressing media, peat and loamy sand, are common in the area east of the park (Dumanski *et. al.* 1972).

### 3.1.1 Peat Topdressings

Peat is a commonly used topdressing material. Almost fifty years ago Feustel and Byers (1936) wrote:

"The use of peat as a source of organic matter for improving the physical condition of mineral soils is becoming increasingly important".

The origin and physical characteristics of peat are important in determining its potential as a topdressing material (Logan 1978). However, with few exceptions, revegetation literature that includes the subject of peat topdressing has failed to accurately describe the medium. This makes comparisons and conclusions difficult. Nevertheless, the addition of peat to the soils at the study site had potential to ameliorate some of the factors limiting revegetation.

The addition of peat to coarse-textured mineral soils has been shown to increase moisture holding capacity (Feustel and Byers 1936, Stevenson 1974). Both the amount of moisture held at field capacity (-0.1 bars moisture tension) and the amount of moisture held at nominal permanent wilting point (-15 bars) have been found to increase with the addition of peat (Feustel and Byers 1936). Stevenson (1974) determined that the increase in water retention results from an increase in the amount of small diameter pore sizes, which are characteristic of humified peat. The small-pores are less easily drained. However, most importantly, the difference between the amount of water held at field capacity and the amount of water held at permanent wilting point (available water) also increases. Fedkenheuer (1979) found that the addition of 15 cm of peat to a coarse-textured tailing sand increased available water from 2.2 percent to a range of 6.5 to 13.3 percent.

The total nutrient content of peat is a function of the content of these materials in the peat forming plants. Generally, peat contains only small quantities of nutrients (Allison 1973, Logan 1978). Massey (1972) demonstrated the lack of nutrients in growth chamber experiments in which peat and tailing sand mixtures required a high rate of complete fertilizer in order to produce adequate growth.

However, the addition of peat to coarse-textured soils can improve fertility indirectly. As organic matter decomposes, the colloidal content of the soil and, consequently, its cation exchange capacity (CEC) increase (Brady 19[illegible]). This improves the ability of the soil to retain [illegible] able plant nutrients that might otherwise be leached out of the rooting zone. Zimmerman and Moore (1974) found that additions of organic matter to mine wastes increased retention of inorganic fertilizer. Furthermore, Fox and Kamprath (1971) found evidence that the addition of organic material to mineral soils may indirectly increase availability of soil phosphorus. They hypothesize that this phenomenon may be due to the decomposiiton of organic matter generating high concentrations of carbon dioxide in the soil. In water, this gas forms carbonic acid, which is capable of decomposing certain primary soil minerals.

Russell (1973) suggested that the most practical means of rehabilitating alkaline soils rich in free lime is the application of large amounts of organic matter. Peats are frequently acidic as a result of low base saturation of the relatively high CEC (Logan 1978). The addition of acidic peat to a coarse-textured soil, with low CEC, can result in a reduction of soil pH (Brady 1974). This could alleviate nutrient availability problems that occur in alkaline soils. Furthermore, the high CEC of peat increases the buffering capacity of the soil to resist increases in pH that can result from calcareous loess deposition (Lucus and Rieke 1968).

While topdressing coarse, rapidly-drained, nutrient-poor, alkaline soils with peat should theoretically improve revegetation success, several experiments have shown contrasting results. Hernandez (1973) found that the establishment of plant cover was significantly more successful on peat soils than gravely soils on sites in the northern boreal forest. Furthermore, Thirgood (1976) found that the application of peat to mine tailings in British Columbia significantly improved plant cover. Logan (1978) found plant biomass yields on Athabasca Oil Sand tailings mixed with several types of peat to be as great as 300 percent of that produced on tailing sands without peat topdressings. Massey (1972) also found that satisfactory plant growth was achieved on Athabasca Oil Sand tailing mixed with 10 to 15 cm of peat, while seedlings on untreated tailing sands failed. Athabasca Oil Sand tailings are very similar to the soils at the study site in that they exhibit low fertility, poor moisture retention properties and high erodibility (Massey 1972, Lesko 1974). While the soluble bases in the Athabasca Oil Sand tailings are predominantly sodium compounds in comparison to calcium carbonates on the montane grasslands, the alkalinity of the tailings immediately after processing is similar to that of the soils at the study site (i.e., pH 8.5) (Rowell 1977, Takji *et al.* 1977). Consequently, micronutrient deficiencies would likely also be similar at both sites.

In contrast, Gosz *et al.* (1978) found that the addition of peat to alkaline, arid mine spoils in southwestern United States caused no significant effects on plant growth. Takyi *et al.* (1977) also found no significant differences in plant growth using various mixtures of Athabasca Oil Sand tailing and peats in their greenhouse experiments. Furthermore, Simard (1968) determined that only extremely large quantities of peat topdressing (47 to 66 cm in depth) improved plant growth significantly. No definitive explanation for these contradictory results can be drawn from the research reports. However, weather, plant materials, original soils depth of application and/or composition of the peat differed somewhat among the the experiments and were likely the reason for the differences. These contradictory results indicate at the usefulness of peat as a topdressing is very site specific.

Peat is not a material indigenous to the montane grassland and its use as a topdressing material can create an artifical and unnatural environment. The physical, chemical and biological properties of peat are radically different from those of adjacent soils. The biotic systems that become established in a soil topdressed with peat may be characteristic of more mesic and more fertile environments than those that occupy the organically-poor soils of the surrounding landscape. Since a management objective of Jasper National Park is to protect and restore natural habitats (Parks Canada 1970), the use of peat topdressing may not be desirable. Furthermore, any seeds or microorganisms contained in an unprocessed peat topdressing would be predominantly those adapted to acidic, hydric environments. They would be unlikely to survive at the study site and, consequently, could not contribute to the colonization and amelioration of the site. Therefore, it was important to study the potential of topdressing with materials that more closely resemble the original surficial material.

### 3.1.2 Loamy Sand Topdressings

The most extensive soil in the area east of the park is loamy sand (Dumanski *et al.* 1972). The loamy sand has properties very similar to those of the undisturbed soils adjacent to the study site and, therefore, may represent a practical alternative to indigenous topsoil.

The application of a loamy sand topdressing to the study site might enhance revegetation potential by creating a gravel-free surface horizon, such as the one that existed prior to disturbance. Loamy sand also has a lower bulk density and provides a more permeable rooting medium than sandy loam and gravel, which were prevalent at the study site. Further, light-colored loamy sand reflects most solar radiation and does not reach temperatures as high as darker peat materials, thus minimizing evaporative losses from the soil.

The vegetation types common to the areas with loamy sand soils are obviously successful in occupying soils with limitations similar to those at the study site. Therefore, any seeds or microbiota contained in the topdressing would be predominantly from species adapted to the xeric environment of the study site.

Sand textured materials have been successfully used as topdressings on mine tailings in the arid, southwestern United States (Aldon and Springfield 1975). Yamamoto (1975) concluded that in the arid mining regions of Wyoming, readily available sandy soils are reasonable alternatives to natural soils. Gould *et al.* (1975) found that topdressing with sandy textured material provided a suitable seedbed on arid mine spoils in New Mexico, if erosion control measures were implemented concurrent with seeding. Walquist *et al.* (1975) found that topdressing with sand increased seedling emergence over that on raw mine spoils. DePuit and Coenenberg (1979) had good success with sandy loam topdressings on stripmine tailings in the semiarid plains of southeastern Montana.

However, loamy sand tends to retain a granular structure and, therefore, is easily eroded by wind (Chepil 1951). Aldon and Springfield (1975) found that burying and abrading of small seedlings by blowing sand can contribute to high seedling mortality. Furthermore, topdressing is an expensive operation which must be justified in terms of increased revegetation success. Therefore, it is also important to examine the potential for revegetation on non-topdressed soils.

### 3.1.3 No Topdressing

Topdressings are added to an area in an effort to simulate topsoil development. However, Weston (1973) found that the soil-building process in nutrient-sterile tailings in western Canada can take place rapidly, under proper management, so that tailings can be productive within three years of the start of reclamation. Caspall (1975) determined that if erosion is controlled under a good cover of grasses and legumes, normal pedological development will produce a soil with sufficient organic matter and other desirable properties to give it characteristics of an A horizon in 20 to 30 years.

Several authors have reported revegetation success on non-topdressed materials. Macyk (1974) had good revegetation results in Grande Cache, Alberta, on an alkaline, organic and nutrient-poor material consisting of a mixture of A, B and C soil horizons. Six years of research in Wisconsin suggested that subsoils consisting of silty sand, gravel, and boulders can be satisfactorily revegetated without topdressing (Brummitt 1976). Furthermore, Caspall (1975) and Wright and Blazer (1981) found that yields on non-topdressed spoils that were properly tilled and fertilized were superior to those on topdressed areas.

Smith and Bradshaw (1972) pointed out that topdressing is often impractical because of cost and availability. Further, Weston (1973) reported that topdressing may actually decrease revegetation success in the long term. Topdressing can create a shallow blanket where plant roots and microbiotic activity concentrate. In such cases, the land is able to support less plant cover, the vegetation is susceptible to even short-term droughts, and erosion control is limited.

## 3.2 Fertilizing

A number of studies have indicated that increases in plant yeilds on disturbed sites can be expected with proper fertilization (Etter 1971, Macyk 1974, Aldon and Springfield 1977, Logan 1978). On stripmine spoils at Grande Cache, Alberta, fertilized plots produced 10 to 20 times [illegible] dry matter than unfertilized plots (Macyk 1974). Et[illegible] (1971) found similar results on stripmine spoils at Luscar, Alberta, as did Takyi and Russell (1980) at Cadomin, Alberta, and Logan (1978) on Athabasca Oil Sand tailings. Increased plant biomass can accelerate soil development and result in greater water holding capacity, better structure and reduced soil erosion (Brady 1974).

The application of fertilizer also has been found to encourage rapid establishment of plant cover. Younkin and Martens (1976) found increases in plant cover ranging from 4 to 66 percent after fertilization with a 1:2:1 mix of N, P and K applied at 440 kg/ha in the Northwest Territories. Bethlahmy (1960) found similar results in coastal British Columbia, and Klock *et al.* (1975) found that fertilization substantially increased emergence, establishment and ground cover of seeded mountain slopes in northern Washington.

However, fertilization has been less effective when other site factors are limiting plant growth. Aldon and Springfield (1977) found no detectable differences in emergence or survival of *Agropyron smithii* Rydb. or *Atriplex canescens* (Purch) Nutt. in experiments on xeric Arizona grasslands, after fertilization with 10-5-5 at 0, 900 and 1800 kg/ha. They did, however, find increases in height and over-dried weight of fertilized plants. These results are similar to their earlier studies, where neither emergence nor early growth of *Secale montanum* L. or *A. canescens* Nutt. were affected by the same fertilizer applications (Aldon and Springfield 1975). Gates (1962) found that the application of fertilizer did little to increase grass emergence and had no effect on seedling survival on a high-altitude Idaho range.

As discussed above, Stringer (1969) and Hettinger (1975) found the soils in the vicinity of the study site to be alkaline and deficient in nitrogen and phosphorus. Cundell (1977) found that application of peat topdressing or organic mulch can result in further depletions of available nitrogen as microorganisms immobilize nitrogen while decomposing the organic matter. Yamamoto (1975) found that nitrogen, phosphorus and sulfur were necessary supplements in order to maintain vegetation on areas that had been topdressed with a sandy material.

Research on similar soils indicated that the application of ammonium nitrogen, completely water soluble phosphorus and sulfate sulfur could alleviate fertility problems. As the nitrogen, phosphorus and sulfur pass into solution, they become available to plants and deficiencies can be overcome. Tisdale and Nelson (1975) found that in arid environments, it is important that the phosphorus be completely water soluble in order to take advantage of the limited soil water. Furthermore, Hausenbuiller (1972) and Russell (1973) found that in alkaline soils, completely water soluble phosphorus enhanced plant growth over less soluble forms.

By reducing soil pH, it is possible to counteract the adverse effects of alkalinity (Tisdale and Nelson 1975). An intensification of soil acidity can be achieved by adding an ammonium-sulfate fertilizer. As ammonium nitrogen converts to nitrate nitrogen, acids are released into the soil medium

(Russell 1973):

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 2H_2O + 4H^+$$

The sulfate in the fertilizer can also be converted to sulfuric acid by autotrophic bacteria (Brady 1974). The acidifying potential of these reactions is reduced when the effect of plant uptake of nitrate nitrogen is considered. As plants absorb nitrate anions, they exchange other anions (e.g., $OH^-$), which can form soil bases (Bidwell 1974). Nevertheless, for every anion exchanged as the nitrate anion is absorb, two hydrogen cations are released through the process of nitrification. Consequently, even when the complete plant-soil cycle is considered, the application of ammonium-sulfate fertilizer will result in acidification of soils. Research on agricultural soils in Alberta has shown that use of ammonium-sulfate fertilizers can result in an acidification of soils (Alberta Soils Advisory Committee 1976).

The rate at which fertilizer has been applied varies greatly. However, research by Brown and Johnston (1978) on high altitude rangelands determined that applications of nitrogen ranging from 55 to 111 kg/ha and phosphorus ranging from 122 to 246 kg/ha were necessary to successfully revegetate the site. Bayne (1975) successfully used 100 kg/ha of nitrogen and 150 kg/ha of phosphorus to grow grass-legume mixes on mine tailings. Aldon and Springfield (1977) applied 180 kg/ha of nitrogen and 180 kg/ha of phosphorus to successfully revegetate an arid grassland.

The timing of fertilizer applications can be critical. Tresler (1974) and Fisser and Ries (1975) found that fertilizing at the time of seeding was necessary to encourage the establishment and growth of sensitive juvenile plants. Bauer *et al.* (1978) found that one heavy application of fertilizer (540 kg/ha of nitrogen) at the time of seeding produced yields equal to those obtained from applying the same amount of fertilizer over periods of three and six years on semiarid mine tailings. Furthermore, research by Zasada (1975), Mains (1977) and Ziemkiewicz (1979) indicated that continued fertilization can inhibit the development of self-sustaining nutrient cycles and homeostasis at the expense of those species best adapated to the natural environment of the area.

The use of fertilizers to establish vegetation on disturbed environments also has negative attributes. Fertilizers are becoming increasingly expensive. Some nutrients may be leached into aquatic systems and may cause eutrophication of adjacent waterbodies and alterations to species composition within these bodies (Hausenbuiller 1972). Fertilization can also create unique biogeochemical soil environments, radically different from those in natural environments (Curry 1975). Furthermore, studies have shown that the addition of fertilizer may become a chronic requirement in order to maintain plant cover (Murray 1973, Ziemkiewicz 1979). If the rate of decomposition of plant matter is slow, the fertilizer absorbed by the plants becomes unavailable. Rowell (1979) found that plants can metabolize up to 160 kg of nitrogen per hectare in one growing season. This explains why in many studies, fertilization has been positively correlated with good inital growth of plants but persistence of the effect is poor (Hull 1974, Younkin and Friesen 1976, Brown *et al.* 1976).

## 3.3 Seeding Methods

### 3.3.1 Seedbed Preparation

Lavin and Springfield (1955), Gomm (1962), Currier (1973) and Selner (1975) found that seedbed cultivation is an essential principle of revegetation. The objectives of cultivation are to permit the seed to be placed in the soil at the desired depth, to allow roots and precipitation to more easily penentrate the soil, and to bury surface materials that could obstruct or hinder seeding operations (Brady 1974). Furthermore, Allison (1973) and Weston (1973) both recommended incorporating topdressings into the underlying material to encourage root development below the topdressing depth.

### 3.3.2 Seed Treatments

Treating the seed prior to seeding is a common agricultural practice. However, very little is known regarding seed treatment requirements for native species, and research by Syncrude Canada Ltd. (1975) and Walker *et al*. (1977) indicated that these requirements will vary among populations. Further research in this area appears important.

Scarification of the hard seed coat of legumes has been found to increase germination of most species. *Astragalus* was found to germinate and become established more successfully when the seed coat was abraded (Grandt 1977). Similar results have also been achieved with *Hedysarum* (Klebesadel 1971).

Most agronomic legumes are innoculated with appropriate mycorrhizal organisms before they are seeded. This ensuress that the legumes will be able to fix atmospheric nitrogen. However, studies by Horstmann (1979) indicated that innoculation of native legumes may not be necessary. It was the opinion of a panel member at a reclamation workshop that innoculum for native plants may be ubiquitous (Vaartnou 1979). Further, little research has been conducted to determine which specific mycorrhizal organisms are beneficial to specific native legumes.

Some research has been conducted indicating a need to stratify shrub seeds in order to enhance germination (King 1980). However, knowledge of stratification requirements is limited and with some species, cold stratification has resulted in significant reductions in germination (Vaartnou 1979).

No previous research was found regarding pretreating grass seeds.

### 3.3.3 Raking

Raking the seed into the seedbed has become very common in revegetation programs, and some authorities have recommended that raking should be considered a standard revegetation practice (Currier 1973, Cook 1974, Sheard and Porter 1977, Johnston and Smoliak 1977, Brown and Johnston 1978). Plummer *et al.* (1955) stated that if the seed cannot be incorporated into the seedbed, then seeding should not be attempted. Walker *et al.* (1977) had little success in establishing grass cover on mountain grasslands in Alberta and wrote:

> "The very low success of establishment..... illustrates the need for covering the seed in some way."

Macyk (1977) compared areas of mine spoils at Grande Cache, Alberta, that were raked after broadcast seeding to areas that were not raked after seeding. He found considerably better grass cover and growth on the raked areas. Einsphar (1955) found that light raking after sowing grasses and legumes more than doubled stand densities on coal spoil banks. Goff (1971) found that plant cover was increased at least 50 percent when seed was harrowed into the soil rather than left on the surface of pipeline and seismic rights-of-way in the Swan Hills of Alberta. McLean *et al.* (1961) failed to establish satisfactory grass cover at Kamloops, British Columbia, unless the seed was covered.

Seed is raked into the seedbed to prevent desiccation of germinating seeds. The surface of the soil often dries rapidly, but moisture loss is considerably slower only 0.5 cm below the surface slower (Russell 1973). This is especially important on coarse soils, such as those at the study site, where large soil pores provide little resistance to vapour transfer and where capillary rise of water to replace that lost to evaporation at the surface is slow (Brady 1974). Johnston and Smoliak (1977) stated that failure to cover seed and subsequent desiccation of the germinants, is a major cause of failure of grassland seeding in Alberta.

Seed is also raked into the seedbed to limit the temperature extremes to which the germinating seed is exposed. Temperature fluctuations decrease with soil depth (Brady 1974). Therefore, by placing the seed below the surface it is possible to reduce the potential for frost damage or lethally high temperatures to the germinant. Again, this can be important on coarse soils, as they dry rapidly and the transfer of thermal energy through large pore spaces is slow.

Seeds are also raked into the seedbed to reduce the amount of seed removed by animals and wind. Birds and small animals can remove and consume large quantities of seed (Hernandez 1973, Walker *et al.* 1977). Because of the low bulk density of seed, it is also susceptible to removal by wind when left on the surface (Currier 1973). Futhermore, Nishimira (1974) noted that the rough surface resulting from raking provides more resistance to wind erosion than a smooth surface.

The depth at which raking places the seed appears critical. Plummer *et al.* (1955) found that optimal seeding depth varied with texture; coarse textured soils required deeper seeding. They also found that large seeds were most successful when seeded at 1 to 2 cm depth while smaller seeds were more successful at 0.5 cm. Sadasivaiah and Weijer (1980) had poor success with species such as *Koeleria cristata* and *Festuca saximontana*, which have small seeds, using a 2 cm planting depth in revegetation trials in Alberta's Rocky Mountains. They concluded that improper depth of seeding was a contributing factor. Similarly, DePuit and Coenenberg (1979) found that species with small seeds did not establish well when planted at 2.5 cm but were very successful when planted at shallower depths.

### 3.3.4 Packing

Several guidebooks have included packing of the seedbed after seeding as a necessary step in revegetation (Lavin and Springfield 1955, McLean *et al.* 1961, Curran and Etter 1974, Johnston and Smoliak 1977, Sheard and Porter 1977, Brown and

Johnston 1978). Packing the seedbed has been suggested as a way to maintain surface moisture (Root 1973, Johnston and Smoliak 1977). Loose soils have large pore spaces which readily conduct water vapour out of the soil (Hausenbuiller 1972). In contrast, small pore sizes inhibit vapour movement. By packing the soil, it is possible to reduce soil pore sizes and consequently reduce evaporative loss of soil moisture. In addition, capillary rise of water is enhanced by compacted soils and reduced pore sizes (Hausenbuiller 1972). Experiments by Mat and Bowen (1963) showed that by compacting a dry surf scil, it is possible to increase soil water sufficiently to allow seed germination.

Packing the seedbed after seeding also ensures good soil-seed contact. Johnston and Smoliak (1977) found that rolling and packing the seedbed after sowing produced a highly uniform, shallow coverage of seed. Firmly packing the soil can increase diffusion and mass flow of nutrients to the roots (Russell 1973). When the soil is firmly packed around each seed, water movement by capillary action from the soil to the seed is also enhanced. Klock *et al.* (1975) determined that poor contact between seed and soil, and consequent low moisture availability, is a major reason for revegetation failure in coarse soils on disturbed mountain slopes.

However, packing the soil may reduce plant available water in the soil. Warkentin (1971) found that compacted soils retain less water at low suction and more water at high suction. This is a result of a reduction in the size of soil pores and subsequent increases in matric potential. Furthermore, by decreasing porosity, packing can inhibit infiltration of precipitation.

Packing the soil may alleviate problems with soil temperature (Russell 1973). As previously discussed, compacting the soil can help maintain moisture near the soil surface. Furthermore, packing can reduce the pore sizes and consequently the ratio of air to mineral component in the soil. Since air is a poor thermal conductor in relation to water or minerals, packing can enhance thermal conduction. Consequently, maximum and minimum temperature extremes are reduced. This can lengthen the growing season and reduce the potential for lethal temperatures (Harrison 1977).

Packing the soil has also been suggested as a means of reducing soil erosion, since loose soils are more easily eroded by wind than compacted soils, within the same textural class (Stallings 1957). Russell (1973) noted that heavy rolling can create a surface crust which is highly resistant to wind erosion. However, as previously mentioned, packing can reduce infiltration and increase overland flow of water which in turn can be erosive. Furthermore, Lavin and Springfield (1955) pointed out that packing operations usually create a smooth surface which offers little resistance to wind or water movement. The result may be greater velocities of wind and water along the soil surface and increased erosion of less compacted areas. Sheard and

Porter (1977) found that if a site is unevenly packed, small depressions and rills can form on the less compacted areas. Consequently, erosion control does not appear to be an important advantage of seedbed packing.

Field trials on arid grasslands in the southwestern United States demonstrated that firm packing of the seedbed greatly improved revegetation survival rates (Merkel 1974). Brown and Johnston (1978) obtained similar results on alpine grasslands in the Rocky Mountains. Lesko (1974) determined that packing the seedbed improved plant cover Athabasca Oil Sand tailing at Fort McMurray, Alberta. In contrast, field trials at Luscar, Alberta, indicated that the advantages of packing were marginal (Lesko *et al.* 1975). McLean *et al.* (1961) found that while packing the ground after seeding usually improved revegetation success on Canadian prairie grasslands, the improvements were not significant.

### 3.3.5 Cellulose Fibre Mulch

There are numerous types of mulches available for revegetation purposes, including straw, wood chips and fibreglass. However Verma and Thames (1978) felt that cellulose fibre is the most common and effective mulch for erosion control and conservation of moisture in arid and semi-arid regions.

Cellulose fibre mulch is applied to a seedbed for many of the same reasons as peat topdressings. However, an important difference between peat topdressings and mulches is that cellulose mulches are usually applied to a seeded surface to protect and ameliorate the underlying seedbed, rather than to provide a seedbed itself. Plass (1978) found that if seed, wood fibre, and fertilizer are applied as a slurry, the sensitive germinating seedlings perched in the porous medium are vunerable to extremes in temperature and to desiccation. Consequently, he believed that, particularly in areas where dry periods can be prolonged, a more effective practice is to apply the seed and fertilizer first and then cover with mulch.

Cellulose fibre mulches have been shown to conserve moisture, particularly at the surface of the seedbed where the seed is germinating (Barkley *et al.* 1965). As with peat, the improved moisture conservation is largely due to the placement of a material with small pore sizes on the seedbed. Smaller pores tend to enhance moisture retention, reduce evaporation and increase available soil water. Also, because the seed is below the surface, moisture fluctuations are not as extreme or as rapid. Barkley *et al.* (1965) measured 12 percent moisture content in the upper 2.5 cm of a soil under cellulose fibre mulch three to four days after irrigation in comparison to 9.4 percent for soils without mulch.

However, studies have shown that it is possible for mulches to actually reduce seedbed moisture levels (Weaver and Rowen 1952). If insufficient moisture accumulates in the mulch to encourage percolation, the moisture will be intercepted and evaporated back to the atmosphere without replenishing soil moisture reserves. Therefore, mulch can be disadvantageous if too much is applied or if the treated area experiences a predominance of light rainfalls. Gardiner (1972) found that mulch did not decrease evaporative moisture loss on revegetated mine spoils in the Rocky Mountains of British Columbia. Furthermore, Verma and Thames (1978) noted that cellulose mulch is, at best, simply a temporary measure in management of moisture conservation.

As discussed in the section on peat topdressings, organic fibres are generally not nutrient rich. Furthermore, since cellulose fibre mulches are usually applied to the surface of the seedbed, the potential for indirect increases in fertility by increasing the CEC of the seedbed is reduced. Cundell (1977) found that mulch may have a negative effect on plant growth one or two years after application, because much of the available nitrogen in the soil is immobilized by microorganisms decomposing the mulch.

Barkley *et al.* (1965) and Curran and Etter (1974) suggest that the most important role of cellulose fibre mulch is to prevent erosion and to hold the seed in place. Cellulose fibre has been found to be effective in control of wind erosion on disturbed lands in arid and semi-arid regions (Verma and Thames 1978). Gould *et al.* (1975) stated that if the surface material is sandy, mulches are necessary in order to stabilize the soil and prevent severe wind erosion. Kay (1978) found that organic mulches protect the soil surface from raindrop impact and subequent erosion and Gardiner (1972) found that mulch was effective at holding seed and soil on steep mountain slopes. Further, by burying the seed, mulches can reduce the amount of seed removed and consumed by birds and animals.

Cellulose fibre mulches have been proven to enhance revegetation success in field trials. Barkley *et al.* (1965) found that two weeks after seeding there were 2.25 times as many grass seedlings on plots mulched with cellulose fibre than on plots without the mulch. Further, they found that the grass seedlings on mulched plots were 66 percent taller and weighed 100 percent more than those on unmulched plots. Gould *et al.* (1975) also reported significantly greater emergence of grasses and forbes on mine spoils in the arid southwestern United States. However, Lesko *et al.* (1975) found that while wood fibre mulch increased soil stability and plant establishment on very steep slopes, it was unnecessary on moderate slopes or flat areas. Weston (1973) suggested that mulches only provide temporary assistance and that it is cheaper to apply more seed and fertilizer.

### 3.3.6 Broadcast Seeding

Broadcast seeding is by far the most common method of revegetating disturbed areas. The main reason is that it is faster and less expensive than any other method. It may be the only practical method of seeding small areas. Weston (1973) noted that because it is not necessary to use ground-based equipment when broadcast seeding, problems imposed by weather, topography or access can be overcome. Consequently, broadcast seeding allows greater flexibility with respect to timing of seeding operations.

A large number of field studies discussed in the previous sections indicated that other seeding methods have been more successful than broadcast seeding (Plummer *et al.* 1955, Johnston and Smoliak 1977, Barkley *et al.* 1965). However, experiments on a high altitude grassland in southwestern Montana conducted by Gomm (1962) showed that initial establishment of grasses was superior when the seed was broadcast rather than drilled on a ploughed and disced seedbed. Drill seeding is similar to covering the seed by raking or with cellulose fibre mulch in that each method buries the seed. DePuit and Coenenberg (1979) compared broadcast seeding to drill seeding on a Montana grassland and found that in all trials, diversity and stand composition was higher under broadcast seeding. They concluded that if establishment of a diverse plant community is a major reclamation goal, then broadcast seeding with proper seedbed preparation generally should be the preferred seeding method. The diverse nature of a plant community established from broadcast seeding is probably a result of increased success of species with small seeds when the seed is left at the surface. Consequently, broadcast seeding may have merits beyond ease of application.

### 3.4 Plant Materials

Native plant materials have been found to be better adapted to poor nutrient conditions than agronomic species (Hubbard and Bell 1977, Walker *et al.* 1977, Ziemkiewicz 1977, Takyi and Russell 1980). Some native plants have shown a greater tolerance to droughty conditions than agronomic species (MacLauchlan 1975, McKell 1978). Johnson and Van Cleve (1976) suggested that native plants tend to create a more stable plant community because of their inherent genetic variability and ecological amplitudes. The phenology of native plants may be better coordinated with the environment of the site than materials evolved in other environments (Johnson and Van Cleve 1976). The timing of flowering can be especially important in this regard, since the growing season in mountain regions is short. Hubbard and Bell (1977) also suggested that native species may be more cold tolerant than agronomic plants and, thus, are better adapted to mountain environments.

Jasper National Park is being managed to preserve and interpret the native plants and animals of the Rocky Mountains (Parks Canada 1970). The study site lies within an area classified as a Natural Environment Area, where maximum protection of natural habitats is provided. Alterations of natural plant and animal habitat functions are discouraged. Persuant to this philosophy, a management program has been developed with the objective of replacing non-native plant species .- native plant species wherever practical (Peepre

1979). Revegetation efforts within the park must be designed to meet these management objectives.

However, there are certain potential disadvantages to the use of native species for revegetation purposes. There is generally a lack of adequate amounts of seed since commercial supplies are limited. Seed from populations local to the disturbed site are often particularly difficult to obtain. Habitat coordinated - genetically controlled variations among populations have been well-documented (Turesson 1922, Gregor and Watson 1954, Syncrude Canada Ltd. (1975). Clausen *et al.* (1940) documented negative plant responses to altitudinal movements of populations. Conversely, Walker *et al.* (1977) found no problems in altitudinal, longitudinal or latitudinal movements of grasses in the Rocky Mountains of Alberta. Their research included numerous species native to the Windy Point study site and they concluded that their plant materials had great enough ecological amplitudes to withstand such movements. There is a need for further research into population-specific definitions of ecological barriers.

Research has also shown that native species are often initially slower growing and produce fewer seed than agronomic species (Johnson and Van Cleve 1976). Furthermore, there is little information on the autecology of native species or their responses to seed treatments (scarification, tratification, innoculation, etc.). There is an obvious need for further research with native plant species to fill these information gaps.

Research indicates that plant diversity may be a key to successful revegetation of disturbed site (Cook 1976, Johnson and Van Cleve 1976). A diverse group of plants has greater genetic variability than a single species. This may enable a diverse community to occupy more micro-habitats than a monoculture and to survive a wider range of environmental conditions. As environment changes through soil-plant succession, disturbance or changes in climate, the inherent variability of a diverse community allows some plants to increase in abundance while others decrease. This is not possible in where a single species occupies a site. A mixed community also has lower susceptibility to species-specific diseases, insect pests or grazing pressures.

If a species is to occupy a site successfully in the long term, it must be able to withstand interspecific competition. When a diverse assemblage of plants is seeded, only those that have the necessary competitive ability will survive. Furthermore, beneficial relationships, such as legumes benefiting grasses through nitrogen fixation, can develop in mixed communities. There are also statistical and experimental advantages to using a mixture of plant materials. Several authors have noted significant differences among plant species and their responses to various revegetation techniques. Plummer *et al.* (1955), Lavin and Springfield (1955), DePuit and Coenenberg (1979) and Sadasivaiah and Weijer (1980) all found significant differences among species in their responses to various seeding methods. Takyi and Russell (1980) found differences among species in the effectiveness of topdressings and fertilizer applications. Further, within any species there exists a great potential for specific populations to vary in their ability to revegetate and reproduce in a given environment (Vaartnou and Wheeler 1974, MacLauchlan 1975, Syncrude Canada Ltd. 1975, Walker *et al.* 1977). Acknowledging potential interspecific variation, it is apparent that if experiments are conducted using only one species (or population), then little can be concluded regarding the value of various techniques to other species. By using several populations and species, it is possible to minimize interspecific effects, thus giving the experimental results broader applicability.

It has been suggested that diversity should be achieved by utilizing species representative of the predominant plant forms native to the site (Cook 1976). At the study site, grasses, forbs and shrubs were abundant (Stringer 1969). Grasses have been found to provide cover more rapidly on disturbed sites than most other plant forms and are effective in stabilizing soils and in encouraging soil development (Hausenbuiller 1972). Moore *et al.* (1975) recommended the use of leguminous forbs in order to provide a long-term source of soil nitrogen. Cook (1976) suggested that both coniferous and deciduous shrubs should be used in revegetation programs. He believed that shrubs provide stability because of longer life cycles than either grasses or legumes.

### 3.5 Experimental Methods

Michaud (1981) suggested that revegetation research commonly requires two sets of experiments. Whenever soil amendments, such as topdressings or fertilizer, are tested, growth chamber trials are necesssary to control environmental variables such as moisture and temperature. Experiments also are required to field test the treatments. Michaud (1981) believed that the field experments should be designed to measure percent ground cover because:

> "It is percent ground cover and not plant densities which determine the effectiveness of vegetation plant cover at protecting the ground surface. If the individual plants provide a small area of protection, a large number of plants is needed to produce an effective ground cover."

Oosting (1956) also suggested that percent ground cover should be measured rather than plant density and concluded that variations in size and form of grasses make counts difficult and of little value.

Measurements of percent ground cover have been made by means of visual estimates in numerous quantitative plant studies (Braun-Blanquet 1932, King and Nicholson 1964, Jensen 1970, Rowell 1977, Wagner *et al.* 1978, Russell and Takyi 1979). Many visual ground cover sampling methods use classes rather than individual percentages (Braun-Blanquet

1932). However, ground cover classes present problems with respect to statisical analysis. Bannister (1966) and Jensen (1970) strongly discouraged the use of classes in favour of estimates made to the nearest percent. One metre square plots have been suggested as an appropriate size from which to esimate ground cover on grasslands (Bannister 1966, Wagner *et al*. 1978, Michaud 1981).

# 4. MATERIALS AND METHODS

In order to test the stated hypotheses, a series of experiments was conducted. A field experiment was used to test the effectiveness of the various treatments in producing increased percent ground cover. A greenhouse experiment was developed in order to control moisture and temperature factors and to measure the degree to which topdressing and fertilizer applications affect plant weight and height. The field experiments could not be used to access plant weight and height because:

1. The experiment was designed to examine long-term as well as short-term results and clippings of the sample plots would have been necessary in order to obtain weight yield data. The clipped plots could not produce seed, contribute organic matter to the soil or compete effectively with invading vegetation.
2. The effect of topdressing and fertilizer applications on plant weight and height could be more efficiently isolated and controlled in a greenhouse environment.
3. Time constraints limited the number of factors which could be measured in the field.

Detailed site analyses including soil tests were conducted, and germination tests were used to assess the germinability of the seed used in the experiments. The latter studies were conducted to improve the information base from which to interpret the results of the two experiments.

## 4.1 Field Experiment

### 4.1.1 Experimental Design

The logistics involved in applying the four independent variables (topdressing, fertilizer, seeding method and plant materials) determined the experimental design. The topdressing had to be applied as a single unit over a large area, since as it was not feasible to apply these materials to randomly located, small discrete units. Similarly, two of the seeding methods (mulching and packing) could not be effectively applied to small units. Therefore, the experiment was designed as a five level split-plot. The split-plot experimental methodology is commonly used on such experiments, for example, the tar sand revegetation projects in Alberta (Rowell 1977, Vaartnou and Sons Ent. Ltd. 1977).

The statistical implication of a split-plot design is that the size of the sampling unit changes among the independent variables (Steel and Torrie 1960). Each independent variable, therefore, has a different sample population and estimate of error. The smallest sampling unit has the smallest population size and it is more difficult to determine the significance of variation. Conversely, relatively subtle differences at the highest order independent variable may be statistically isolated.

The field experiment at Windy Point was designed such that the order of independent variables from highest to lowest was:

1. Topdressing effect (3 variables)
2. Fertilizer effect (2 variables)
3. Seeding method effect (4 variables) and
4. Plant material effect (3 seed mixture variables and 16 species variables).

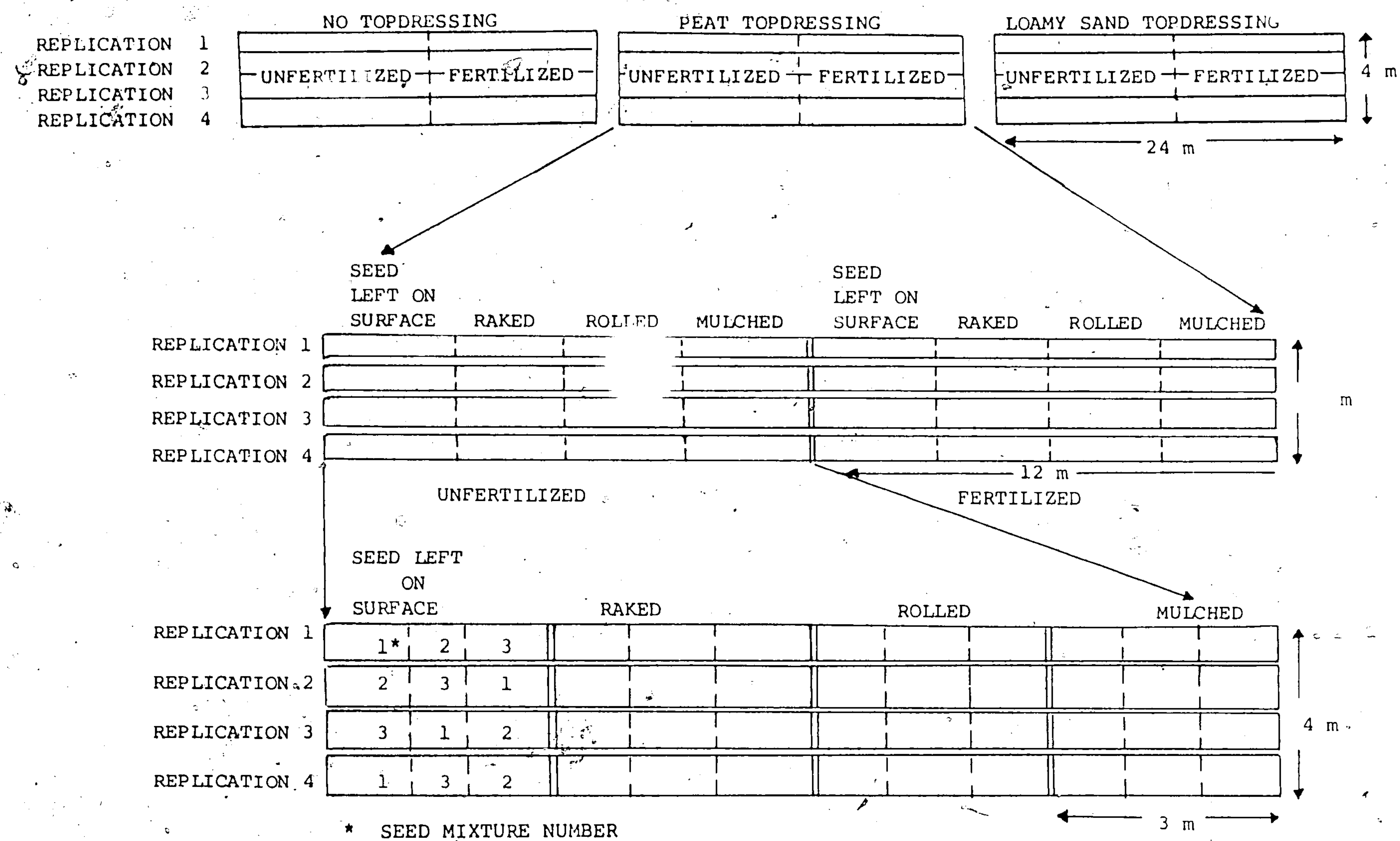
This order reflected the logistical considerations in applying the treatments.

### 4.1.2 Plot Establishment

In late May and early June of 1977, 288 plots one square metre in size were measured and staked-out along the pipeline right-of-way. The number of replications was limited by the width of the right-of-way and the length that was suitably level. The site was divided into four replications (rows) and then further subdivided into four levels of plot units which represented the four independent variables (Figure 4).

The preparation of the seedbed was an experimental constant for the field study. Once the replication and topdressing units h[illegible]en established, the entire study area was hand rotot[illegible]ce. Other than for the reasons described in the [illegible]ure review (Section 3.3.1), the objectives of the rototilling were also to eliminate established vegetation which might cause a statistical bias and to bring the underlying finer-textured soil particles to

FIGURE 4: Schematic Field Experiment Plot Design



the surface. The two rototillings were done perpendicular to each other to provide more effective coverage. All of the plots were then hand raked to create a level seedbed and to remove surficial rocks, branches and roots. The raking ensured that all plots had roughly equal seedbed surfaces and exposures.

The plots topdressed with the loamy sand and those not topdressed were seeded June [illegible] 1977. Delivery of the peat topdressing was delayed due to inclement weather. Consequently, the plots topdressed with peat were not seeded until June 14, 1977. Approximately four man weeks were required to establish the plots and apply the treatments.

#### 4.1.2.1 Topdressing Treatments

The source of the peat topdressing was an area of organic soils southwest of Hinton, Alberta, where the peat was being mined for topdressing residential landscapes. The location of the peat source is an area where organic soils belong to the Fickle soil complex (Dumanski *et al.* 1972). Fickle soils are characterized by the presence of greater than 60 cm of unconsolidated peat which is derived primarily from semi-decomposed feather mosses and, to a lesser extent, sphagnum mosses. The peat consisted of an approximately equal mixture of fibric and mesic organic matter that was dark reddish brown to very dark gray in color. The peat was not commercially processed.

Loamy sand topdressing was taken from a site approximately [illegible] km west of Hinton, Alberta. Soils of the Hinton association occupy the area (Dumanski et al. [illegible]). The parent material of the Hinton association soils has been described by Dumanski et al. ([illegible]):

> medium textured, strongly calcareous, grayish brown, aeolian material which covers the landscape in the form of a loess-like blanket.

The soil was [illegible] to loose in consistency and completely gravel-free.

The four replications were divided into three topdressing treatments. One subdivision received a 10.0 cm cover of peat, another received a 7.5 cm cover of loamy sand and the third subdivision was not topdressed. The volume of topdressing was determined by the size of truck that could travel on the narrow, gravel road to the study site. The North Dakota Agriculture Experiment Station (1975) had satisfactory responses with topdressings as thin as 5 cm and Tresler (1974) had successfully used 10 cm of sandy loam topdressings when the underlying material was not toxic. Further, Berry (1970) found that a 10 cm topdressing of peat improved water holding capacity, increased retention of plant nutrients by the soil, accelerated seed germination and increased plant survival rates on Athabasca Oil Sand tailings.

### [illegible] Fertilizer

The topdressing units were divided into fertilized and unfertilized halves. Ammonium-phosphorus-sulfate ([illegible]) was broadcast on the fertilized plots at [illegible] kg/ha as recommended by Brown and Johnston ([illegible]). This yielded [illegible] kg/ha of nitrogen, [illegible] kg/ha of phosphorus and [illegible] kg/ha of sulfur. Fertilizer was applied only once at the time of seeding, as recommended by Zasada ([illegible]).

### 4.[illegible].3 Seeding Method Treatments

The fertilizer treatments were further divided into four seeding method units. Seed was applied at 20 kg/ha which is similar to rates recommended by the Alberta Forest Service (1979). The seed coats of legumes were abraded with sandpaper prior to seeding, but the seed was not innoculated. The seeds of the shrub species were not stratified and no treatment was applied to the grass seeds.

The seeding methods tested were:

1. broadcast seeding (leaving the seed on the soil surface),
2. hand raking the seed into the seedbed,
3. packing the seed into the seedbed with a 100 kg roller, and
4. covering the seed with a cellulose fibre hydromulch (the commerical brand "Conwed Hydro mulch").

The mulch was applied as a water slurry at a rate of 1875 kg/ha as suggested by Cook (1976) and was within the range recommended by Kay (1976). The resulting mulch cover averaged 5 cm in depth. However, since the mulch was applied by hand, the cover varied within each plot and ranged from 1 cm to nearly 8 cm in depth.

4.1.2.4 Plant Materials

The seeding method units were ultimately subdivided into one metre square plots which were used to determine the effect of each treatment on the plant materials.

Seed from populations at or in the vicinity of the study site were not available. Recognizing potential problems with using non-localized populations, it was necessary to carefully select candidate plant materials based on four criteria:

1. Past research on sites with similar environments and limitations had to have indicated that the plant material had good potential to revegetate the study site. This information was derived from my personal experience with the plants and experiences of Dr. Vaartnou who collected and propagated the materials (Vaartnou and Wheeler 1974, Vaartnou and Sons Ent. Ltd. 1976, 1977). However, at the initiation of the Windy Point field trials, the information base for these plant populations was limited. Consequently, revegetation research literature for other populations of the same species had to be heavily

utilized.

2. It was desirable to develop a community with floristic characteristics similar to communities indigenous to the area. Such a community would meet the objectives of the revegetation program of Parks Canada (Parks Canada 1970, Peepre 1979) as well as appear more natural and less conspicuous to the average park user. Consequently, species native to the study site were considered most desirable.
3. As discussed in Section 3.4, a diversity of plant forms including grasses, legumes and shrubs was desired.
4. The plant materials had to be available. Until recently, there has been a lack of interest in developing native plant materials for revegetation purposes. Sufficient quantities of seed for many species that may have been suitable for revegetation at the field experiment site were not available. Consequently, some less desirable species were selected from the best available alternatives.

A detailed analysis of suitability for all available plant materials was conducted. Appendix B provides the results of this analysis for those species used in the field experiments.

The statistical advantages of using a large number of species were described in Section 3.4. Sixteen populations, representing fifteen species were selected for the field trials and are listed in Table 2. Two populations could not be taxonomically classified at the species level and the origin of one population of *Poa alpina* was unknown. The sixteen populations were divided into three seed mixtures. Consequently, the number of species in each seed mixture conformed to that used in most revegetation programs (Hernandez 1973, Klock *et al.* 1975, Cook 1976, Younkin and Martens 1976, Alberta Forest Service 1979). If a single large seed mixture had been used, the amount of seed of any one species sown on a given plot might have been insufficient to provide adequate dispersal. Further, ground cover for each species was more easily assessed when fewer species occupied a given plot.

The species were randomly assigned to a seed mixture according to the following criteria:

1. Each mixture had at least one tall grass species (i.e., *Agropyron trachycaulum*, *A. riparium*, *A.* sp. or *Elymus innovatus*),
2. Each seed mixture had at least one short grass species (i.e., *Poa alpina*, *P. pratensis*, *Festuca saximontana*, *Koeleria cristata* or *Agrostis stolonifera*),
3. Each seed mixture had one legume species, (i.e., *Astragalus* sp., *Hedysarum alpinium* or *H. mackenzii*).
4. Each seed mixture had one shrub species (i.e., *Juniperus horizontalis*, *Rosa acicularis* or *Elaeagnus*

Table 2: Plant Materials Used in Field Experiments

| Species | Origin of Seed Stock | Native to Study Site Area | Drought Tolerant | Alkaline Tolerant | Nitrogen Fixer |
|---|---|---|---|---|---|
| Juniperus horizontalis Moench. | Kooteney Plains, Alberta | Yes' | Yes | Yes | No |
| Agropyron riparium Scribn. & Smith. | Oregon (cv. Sodar) | Yes' | Yes | Yes | No |
| Agropyron trachycaulum (Link) Malte | Beaverlodge, Alberta | Yes' | Yes | Yes | No |
| Agropyron sp. | Beaverlodge, Alberta | -- | -- | -- | No |
| Agrostis stolonifera L. | Poland | No | [illegible] | -- | No |
| Elymus innovatus Beal. | Ft. St. John, B.C. | Yes'' | [illegible] | -- | No |
| Festuca saximontana Rydb. | Kootenay Plains, Alberta | Yes' | [illegible] | -- | No |
| Koeleria cristata (L.) Pers. | Peace River, Alberta | Yes'' | Yes | Yes | No |
| Poa alpina #1 L. | Pine Pass, B.C. | No | Yes | Yes | No |
| Poa alpina #2 L. | Unknown | No | Yes | Yes | No |

| | | | | | |
|---|---|---|---|---|---|
| *Poa pratensis* L. | Palmer, Alaska | Yes[3] | Yes | Yes | No |
| *Rosa acicularis* Lindl. | Cypress Hills, Alberta | Yes[1,2,3] | Yes. | Yes | No |
| *Astragalus* sp. | Kootenay Plains, Alberta | -- | -- | -- | Yes |
| *Hedysarum alpinum* L. | Peers, Alberta | Yes[1,3] | Yes | Yes | Yes |
| *Hedysarum mackenzii* Richards. | Haines Jct., Yukon | Yes[2] | Yes | Yes | Yes |
| *Elaeagnus commutata* Bernh. | High Level, Alberta | Yes[3] | Yes | -- | Yes |

[1] Identified by Stringer (1969).

[2] Identified by Hettinger (1975).

[3] Identified by Wells *et al.* (1978)

[4] Insufficient information.

*commutata*).

Since available seed stocks were limited, it was necessary to use two tall grass species in one seed mixture and three short grass species in another in order to equalize the seed mixture weights. An attempt was made to equalize the number of small and large grass seeds by increasing the weight proportion of the heavier, large seeds. The composition of the three seed mixtures is shown in Table 3.

The experiments were designed to determine the effects of the various treatments on vegetation as a whole and to determine the effects of the treatments on individual species. It was assumed that no seed mixture was superior to another as all contained sufficient plant diversity to overcome the lack of success of any one species. Since different quantities of seed were used for each species, no comparison of responses among species could be made. However, differences in morphologies and physiologies among the species would likely make such comparisons invalid.

### 4.1.3 Sampling Methods

After the field plot experiments had been established a sampling program was initiated. The site was visited on five occassions in the first growing season: July 15, July 22, July 28, August 11 and August 17, 1977. The plants were generally too immature throughout this period to accurately

Table 3: Composition of Seed Mixtures Used in Field Experiments

| Seed Mixture 1 | Percent of Total Weight |
|---|---|
| *Agropyron trachycaulum* | 30% |
| *Elymus innovatus* | 30% |
| *Poa alpina #1* | 20% |
| *Hedysarum mackenzii* | 10% |
| *Juniperus horizontalis* | 10% |

| Seed Mixture 2 | |
|---|---|
| *Agropyron riparium* | 30% |
| *Koeleria cristata* | 20% |
| *Poa pratensis* | 20% |
| *Agrostis stolonifera* | 10% |
| *Astragalus sp.* | 10% |
| *Rosa acicularis* | 10% |

| Seed Mixture 3 | |
|---|---|
| *Agropyron sp.* | 30% |
| *Festuca saximontana* | 30% |
| *Poa alpina #2* | 20% |
| *Hedysarum alpinum* | 10% |
| *Elaeagnus commutata* | 10% |

identify species. Consequently, quantitative analyses were not warranted. Instead qualitative assessments regarding germination and initial establishment were made.

Research by Selner (1975) showed that most grasses and legumes can germinate and grow in the first year; however, growth of unsuitable species can be drastically reduced by the second growing season. Consequently, it was assumed that the second growing season could provide a measure of the effectiveness of treatments.

The study site was sampled four times during the 1978 growing season: June 3-6, June 28-30, July 25-27 and September 2-5. During the first three sampling periods, the amount of plant ground cover was estimated to the nearest percentage for each seed mixture. This was necessary since many of the plants had not fully developed and, consequently, species identification was inaccurate. However, by early September it was possible to identify the individual species, since most plants had completed vegetative development and had flowering parts. Therefore, percent ground cover was estimated for each species as well as for the seed mixture during the September evaluations. Non-seeded, invader species were also included in each estimate of total ground cover in a plot. The presence of these species can also be a measure of the effectiveness of the treatments. Dr. Vaartnou provided on-site verification of species identification (Vaartnou pers. comm.).

As previously noted, height and weight data could not be collected from the field experiments. However, general notes were made concerning height, vigor and seed production of the plants during each of the evaluations.

### 4.1.4 Statistical Analysis

Ground cover data from the field experiments were analyzed using multiple analysis of variance (Steel and Torrie 1960). The statistical significance of treatments and interactions were determined on the basis of F table values at the 1 percent ($P \leq 0.01$) significance level. The means of all treatments that were significant at $P \leq 0.01$ were statistically compared using Duncan's Multiple Range Test (Duncan 1955) ($P \leq 0.01$). Duncan's Multiple Range Test is one of the most common methods of multiple comparisons in biological experiments (Hardin 1978). Using a common method allows comparisons to be made more readily with other experimental results.

Analyses were conducted for the data in which ground cover was estimated for each seed mixture. A separate analysis was also conducted on the data set collected at the end of the field experiments in which ground cover was estimated for each species. This analysis permitted an evaluation of the effect of the treatments on individual species.

## 4.2 Greenhouse Experiments

### 4.2.1 Experimental Design

The greenhouse experiment was designed as a three-way analysis of variance with three topdressings treatments, two fertilizer treatments and five species. The amount of available greenhouse space and facilities limited the total population size.

At the end of the field experiments, soil was collected in the field from the unfertilized portions of each of the topdressing treatments (peat topdressing, loamy-sand topdressing and no topdressing). The soils were air dried and all gravel and roots were removed. Each of the three soil materials was placed into ten separate, 13.35 cm diameter, free-draining pots. The thirty pots were then saturated with water and the soils were allowed to settle. Soil was added as necessary to equalize the volume of soil in each pot.

Ammonium-phosphate-sulfate fertilizer (16-20-0 + 14%S) was added to half of the pots in each topdressing treatment. Fertilizer was applied to the soil surface at a rate of 785 Kg/ha, duplicating those rates used in the field.

Five grass species were randomly selected from those used in the field experiments. The species used were:

1. *Agropyron riparium*
2. *Agropyron trachycaulum*
3. *Agrostis stolonifera*

4. *Poa alpina #1*
5. *Poa pratensis*

Grass species were selected because their seeds generally do not require treatment prior to seeding and they germinate and grow more frequently than legumes or shrubs. Each species was randomly assigned a row in each pot. By seeding all of the tested species in each pot, the effects of interspecific competition could be included and field conditions more closely simulated. Ten seeds of each species were sown 0.5 cm below the soil surface in each pot. Each species was subsequently thinned to five plants per pot, in stages one, two and three weeks after seeding. By overseeding and thinning it was possible to eliminate differences in seed viability. At least five plants per species germinated and grew in each pot. The pots were randomly located on the greenhouse bench in order to avoid statistical bias. The pots were watered to field capacity twice a week, so that moisture stress of the soils was not significant at any time.

### 4.2.2 Sampling Methods

The experiment was initiated on September 26, 1978 and continued for twenty-one weeks, which is approximately the effective growing season for Jasper, Alberta (Boughner 1964). During this period, the greenhouse was having problems with environmental control, and temperature, humidity and light intensity varied considerably over this period. Temperature averaged 16-18°C but varied from 7° to 23°C. At 7°C the roof of the greenhouse frosted heavily and the intensity of light decreased.

Twice a week, height measurements were recorded for each plant and notes were made regarding nutrient deficiency symptoms, flowering and seed production. At the end of twenty-one weeks, the plants were clipped at ground level, since the roots could not be separated effectively. All the above-ground parts of each species in each species were collectively oven-dried and weighed. Individual plants were not weighed as they were too light for accurate measurements.

### 4.2.3 Statistical Analyses

The weight and height data were separately analyzed using multiple analysis of variance (Steel and Torrie 1960). Statistical significance of independent variables was determined by F tests at the 1 percent ($P \leq 0.01$) significance level. The means of all significant variables were compared using Duncan's Multiple Range Test (Duncan 1955)($P \leq 0.01$).

## 4.3 Site Data Collection

Soil pits were dug along the right-of-way in the spring of 1977, prior to treatment, so that profile descriptions of the original seedbed could be made. Soil samples were collected from each of the six fertilizer treatment plots in the fall of 1978. Each sample represented a composite of ten separate samples collected from random locations within each fertilizer treatment. Separate samples were taken for the 0 to 15 cm and 16 to 30 cm depths at each location. All samples were air-dried and broken into granular structure. Chemical and physical analyses were conducted by Alberta Agriculture's Soil and Feed Testing Laboratory.

Original plant cover at the study site was determined by estimates of percent ground cover for ten, one metre square plots. Observations were recorded concerning grazing at the study site. Weather data were collected from published reports for Jasper townsite for both years the field experiments were conducted (Environment Canada 1977, 1978).

## 4.4 Germination Tests

Since standardized germination tests had not been developed for any of the native species used in the experiments, the tests could not be modelled after any proven germination method. Consequently, the following germination test was conducted for all species used in the field experiments. The seeds were first placed in a solution containing 1.5 percent hydrogen peroxide for 15 minutes in order to eliminate fungal microorganisms which might have inhibited germination. The seeds were then rinsed with distilled water. The seeds of the three legume species were scarified with sandpaper to abrade their seed coats as was done in the field experiments. Twenty-five seeds of each specie were placed in each of two petri dishes lined with filt[illegible]. The dishes were then placed in a warm (18-[illegible]°C), dark cupboard, and moisture was added daily as required. The dark, warm environment was used to simulate seedbed conditions below the soil surface.

Records were made as to the number of seeds that had germinated 5, 10, 15, 20 and 30 days after the initiation of the tests. A seed was counted as having germinated when the radicle length was twice the diameter of the seed. Due to limitations in the quantity of available seed and facilities, only one replication could be accommodated and no statistical analyses were conducted.

# 5. RESULTS AND DISCUSSIONS

The results of the soil tests are provided in Appendix C. Analyses of variance for the field and greenhouse experiments are included in Appendix D. The following sections discuss the environmental conditions that affected the experimental results, the germination test results and the effectiveness of the treatments. Certain statistically significant tertiary and higher level interactions are not discussed in this report. These higher level interactions generally were concerned with the responses of individual species to multiple treatments. However, these higher level interactions were too complicated to allow interpretation from the data collected. These interactions were isolated in order to obtain the estimates of error in the split-plot design and to allow a more precise definition of variance of main treatment effects.

## 5.1 Site Analysis

### 5.1.1 Weather

Meteorological data for 1977 and 1978 are presented in Table 4. These data were recorded for Jasper townsite which may be more mesic than the study site. However, the data are useful in describing the general weather conditions at the study site relative to the long term average.

The weather for the 1977 and 1978 growing seasons (May to September inclusive) was more conducive to the

Table 4: Meteorological Data Recorded for Jasper, Alberta (1977-78).

**YEAR 1977**

| | JAN | FEB | MAR | APRIL | MAY | JUNE | JULY | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Precipitation (mm) | 7.5 | 11.3 | 20.5 | 11.1 | 50.9 | 34.0 | 88.5 | 57.4 | 54.3 | 26.5 | 30.0 | 24.3 | 416.3 |
| Percent of Norm | 25 | 47 | 139 | 49 | 146 | 68 | 186 | 120 | 156 | 88 | 92 | 74 | 97 |
| Snowfall (cm) | 4.4 | 5.0 | 28.0 | 7.0 | 12.2 | 0.0 | 0.0 | T[1] | 3.2 | 1.6 | 31.6 | 36.6 | 130.3 |
| Mean Temperature(°C) | -8.4 | -0.2 | -1.4 | 5.3 | 8.2 | 13.1 | 13.5 | 14.0 | 8.2 | 4.2 | -5.5 | -15.0 | 3.03 |
| Difference from Norm | +3.8 | +6.8 | +1.3 | +2.0 | -0.5 | +0.6 | -1.7 | -0.1 | -1.7 | -0.6 | -1.7 | -5.9 | +0.2 |
| Maximum | 8.3 | 11.3 | 8.8 | 26.5 | 20.7 | 29.4 | 30.1 | 29.3 | 21.4 | 19.6 | 12.2 | 2.6 | 30.1 |
| Minimum | -27.9 | -12.0 | -15.8 | -9.2 | -2.3 | 1.5 | 1.7 | 2.2 | -1.3 | -7.3 | -28.0 | -38.5 | -38.5 |

**YEAR 1978**

| | JAN | FEB | MAR | APRIL | MAY | JUNE | JULY | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Precipitation (mm) | 12.4 | 1.0 | 14.0 | 41.3 | 40.7 | 66.2 | 96.4 | 34.2 | 107.6 | 33.2 | 21.7 | 10.3 | 479.0 |
| Percent of Norm | 41 | 4 | 95 | 183 | 117 | 133 | 203 | 71 | 309 | 110 | 67 | 31 | 112 |
| Snowfall (cm) | 16.0 | 1.2 | 0.4 | 16.6 | T | 0.0 | 0.0 | 0.0 | T | T | 10.6 | 15.8 | 60.6 |
| Mean Temperature(°C) | -14.3 | -6.6 | 0.2 | 4.6 | 7.9 | 13.3 | 16.0 | 13.7 | 8.8 | 5.8 | -5.4 | -10.2 | 2.8 |
| Difference from Norm | -2.1 | 0.0 | +2.8 | +1.3 | -0.8 | +0.8 | +0.8 | -0.4 | -1.1 | +1.0 | -1.7 | -1.2 | 0.0 |
| Maximum | 2.1 | 9.8 | 12.4 | 20.4 | 22.6 | 29.4 | 31.2 | 31.0 | 17.2 | 19.1 | 12.7 | 4.4 | 31.2 |
| Minimum | -29.4 | -35 | -24.2 | -7.6 | -4.2 | 1.4 | 5.2 | 3.2 | -2.5 | -6.2 | -26.6 | -33.6 | -33.6 |

Source: Environment Canada 1977, 1978

[1] T = Trace

establishment of vegetation than the 30 year average. In 1977, precipitation was 200.2 mm (54 percent above average) from the end of June, (at which time seeding had been completed) to the end of September. The May to September precipitation in 1978 was 345.1 mm, which is 61 percent above the 30 year average. Further, mean temperature in 1977 was 3.4°C below and in 1978 slightly below the 30 year average for May to September. Consequently, evapotranspirative demands for soil moisture would not be as great as those in an average year. It is probable that above average precipitation, in conjunction with below average temperatures, produced a more favourable moisture regime at the study site than normally exists. This has important implications to the interpretation of results discussed below.

Frost was recorded in all months except June, July and August in both 1977 and 1978. Temperature extremes were large as maximum temperatures exceeded 30°C and minimum temperatures were below -30°C in both years. The winter of 1977-78 (November to March) was 6.9°C colder than normal, with an average temperature of -8.3°C. Total snowfall was 85.8 cm, which is 61 percent of normal. The insulative property of snow to the soil surface would not be as great under these conditions. This indicates that the winter season between the initiation and conclusion of the field experiments was somewhat more severe than the 30 year average. Such conditions provided a test of winter hardiness of the plants.

### 5.1.2 Soils

Random profile examination of the undisturbed areas adjacent to the study site found the soils to have a thin (2 to 10 cm depth), dark grayish brown, AhK horizon directly overlying a CK horizon of unknown depth. Both horizons are generally structureless with single-grain particles being predominant. The Ahk horizon is gravel-free, sandy loam in texture and is well to rapidly drained. The subsurface CK horizon has about 10 percent gravel by volume and is a well drained, loam. These observations are similar to those made by Stringer (1969) and Hettinger (1975) for their studies of soils in the area. Although Hettinger (1975) and Wells *et al.* (1978) observed Ahb horizons in the area, no buried Ah horizons were observed in the undisturbed soils adjacent to the study site. This suggests that Orthic Regosols are the predominant soils and that loess deposition is relatively continuous.

The soil of the study site (along the pipeline right-of-way) lacked development of soil structure and did not have defined profiles. The activities associated with the construction of the pipeline had resulted in the incorporation of the developed horizons with the underlying undeveloped, parent material. The process of soil development, which is inherently slow in the area, had not progressed appreciably in the 25 years since disturbance. To a 60 cm depth, the surficial regolith consisted of a light grayish brown, well to rapidly drained, sandy loam material. The material was intermixed with approximately 20-35 percent (by volume), gravel-sized material. Probably as a result of erosion and frost heaving, the gravel covered approximately half of the surface of the study site. Drainage along the right-of-way is likely more rapid than on adjacent, undisturbed areas that have a finer-textured subsurface horizon.

Chemical analysis of the soils at the study site and on adjacent undisturbed lands indicated that both soils are nutrient poor, especially with respect to available nitrogen and phosphorous. Pipeline construction does not appear to have affected the chemistry of the soils. Both soils are slightly to non-saline, and are moderately to strongly alkaline. Soil alkalinity appears to increase with depth. Concentrations of free lime are very high at all depths. Since calcareous loess deposition at the study site appears to occur on a continuous basis, it is probable that fertility problems associated with alkalinity and high levels of free lime will be persistent.

Organic matter in the soil can act as a nutrient reserve. Optimally, a plant-nutrient cycle exists whereby release of available nutrients from decomposition of organic matter equals detrital input from the plants and contributes significantly to the fertility of the soil. However, soil organic matter content and live plant biomass at the study site were very low, indicating that organic nutrient reserves were severely limited. Furthermore, the influence of nitrogen fixing microorganisms was probably negligible, since, with few exceptions, leguminous plants were absent from the study site.

The coarse texture and low organic content of the soils of the study site indicate that their CEC is low. Consequently, it is probable that the soils at the study site are unable to retain a large portion of the nutrients that do become available. This characteristic compounds soil nutrient problems.

As previously discussed, the soils at the study site are highly susceptible to wind erosion. Erosion can limit revegetation potential by removing the developed soil materials from the surface of the site, leaving behind less developed soils and gravel as a growth medium. Further, the movement of the coarse soil particles can abrade or bury emerging seedlings. This action can reduce productivity or result in the death of the plant. The extent of gravel on the surface of the study site suggests that erosion had been an important factor since the inital disturbance by pipeline construction. However, at the end of two growing seasons, signs of erosion, such as exposed root crowns or decreased depth of topdressing materials, were not observed. This suggests that in the short time period that the experiments were conducted erosion was not an important factor affecting the field results. The lack of erosion may be due largely to the higher than normal precipitation recorded in the area during the two growing seasons. Moist soils are generally less susceptible to wind erosion than dry soils (Stallings 1957).

The porous, well-drained surface soils at the study site can heat and cool rapidly because transfer of thermal energy to and from lower soil depths must be conducted largely through air. Air is a poor thermal conductor relative to water or minerals (Brady 1974). This can result in frequent incidence of frost and, perhaps, lethally high soil temperatures. However, the soils likely remained moister than normal as a result of above average precipitation in both growing seasons. The potential for lethally high soil temperatures was also diminished as a result of below-normal temperatures in both 1977 and 1978. Furthermore, Lesko *et al.* (1975) found that lethally high soil temperatures did not occur in revegetation trials at Grande Cache, Alberta, and Deely and Borden (1973) found that it is unlikely that light colored soils, such as those indigenous to the study site, will reach lethal temperatures.

Consequently, it appears that there are no soil factors other than low fertility and periodic moisture stress that may have interferred with normal plant growth.

### 5.1.3 Vegetation

Prior to treatment, plant cover at the study site was found to vary from 0 to 30 percent. The average plant cover for the study area was 9.5 percent. In comparison, Stringer (1969) determined that mean plant cover in the adjacent undisturbed grassland was 80 percent.

The availability of plant material to naturally colonize the study site was limited. The short grasses are known to produce low quantities of seed and viability of the seed is inherently poor (Walker *et al.* 1977). The strong winds common to the area likely blow some of the seed off the site. Furthermore, overgrazing by native ungulates can severely restrict seed production (Johnston *et al.* 1981).

### 5.1.4 Grazing Activities

Throughout both growing seasons, grazing by sheep and elk was evident. Approximately five bighorn sheep were frequently observed grazing at the test plots and appeared to be summer residents. While no elk were observed at the site, their feces were common. No evidence of deer, moose or horse grazing was observed and no ground squirrels (*Spermophilus columbianus* Ord.) were found in the area.

While some grazing was evident on all treatment plots, the intensity of grazing appeared to be somewhat selective. The fertilized plots appeared to be more heavily grazed than the unfertilized plots. Peat topdressed plots were grazed more than the loamy sand or the non-topdressed plots.

Similarly, certain species such as *Poa pratensis* were more frequently grazed than others such as *Agropyron trachycaulum*.

The implications of selective grazing are very significant. By selectively consuming certain palatable species, grazing animals can alter community composition. Heavily grazed, open areas lack the plant cover necessary to minimize soil temperature extremes or to trap moisture. They are generally droughtier, hotter during the day and more prone to early and late frosts than similar sites that are lightly grazed (Johnston *et al.* 1981). Furthermore, by removing a significant portion of the plant biomass, grazing can reduce the amount of organic matter in the soil. Soils with sufficient organic matter generally retain more mositure, are more productive and are less susceptible to erosion (Brady 1974).

Grazing can also affect the ability of the plants to reproduce and survive. Heavy grazing severely restricts seed production and Johnston *et al.* (1981) reported that moderately grazed plants produced 12 times as much root biomass as heavily grazed plants. This in turn reduces the drought-tolerance of the plants

Hernandez (1973) suggested that plant-animal interactions are probably one of the most critical and least understood aspects of revegetation. While an important objective of revegetation can be to provide grazing material, any treatment that encourages overgrazing will likely be unsuccessful in the long term.

## 5.2 Germination Tests

The results of the germination tests are given in Table 5. Under the treatment imposed, there was wide variability among species with respect to the percentage of seeds that germinated and the rates at which germination occurred (Figure 5). The grass species with the largest seeds (*Agropyron riparium*, *A. trachycaulum*, *A.* sp. and *Elymus innovatus*) had the highest percentage of seed that germinated (87 percent). In contrast, grass species with the smallest seeds (*Agrostis stolonifera* and *Koeleria cristata*) had the poorest germination (22 percent). However, ten days after initiation of the test, 84 percent of the small seeds that would germinate under the germination treatment used had done so, compared to 37 percent for intermediate-sized seeds and 21 percent for large seeds.

The poor germination of small seed is probably partially related to the manner in which the seed had been stored and handled. All grass seed had been stored in aerobic conditions, at room temperature and was subject to fluctuating humidity. These conditions can result in oxidation of reserved food supply in the seed (Bidwell 1974). The loss of stored food would be of greater significance to smaller seeds, which lack the quantity of food of the larger seeds. Consequently, many of the small seeds may not have been viable.

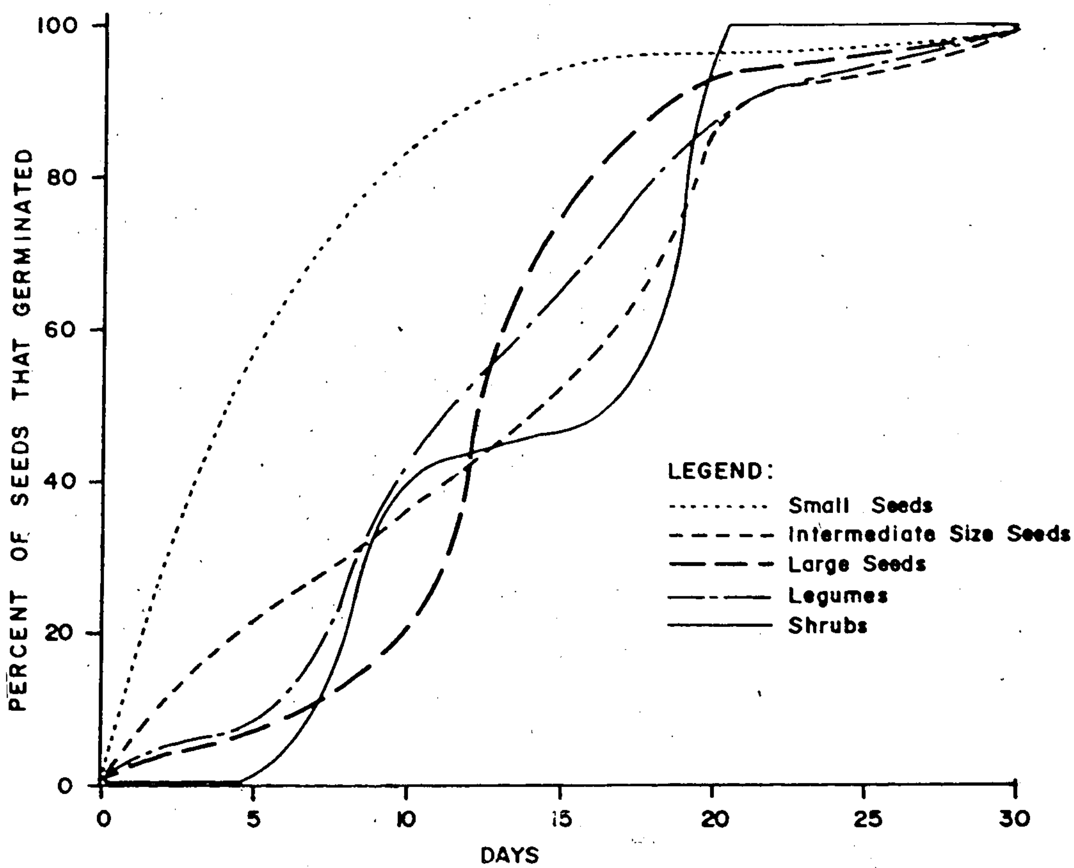
Table 5: Germination Test Results Expressed as a Percentage of Total Population

| Species | Days After Initaιιon of Germination Test | | | | |
|---|---|---|---|---|---|
| | 5 | 10 | 15 | 20 | 30 |
| 1. Large Seed Grasses (> 2.0 gm/1000 seeds)[1] | | | | | |
| *Agropyron riparium* | 8 | 20 | 72 | 100 | 100 |
| *Agropyron trachycaulum* | 2 | 18 | 80 | 90 | 98 |
| *Agropyron sp.* | 2 | 12 | 66 | 70 | 82 |
| *Elymus innovatus* | 12 | 20 | 50 | 62 | 68 |
| **Average** | **6** | **17.5** | **67** | **80.5** | **87** |
| 2. Intermediate Seed Grasses (0.4 to 0.7 gm/1000 seeds) | | | | | |
| *Festuca saximontana* | 2 | 10 | 12 | 32 | 38 |
| *Poa alpina #1* | 22 | 36 | 48 | 52 | 68 |
| *Poa alpina #2* | 18 | 28 | 44 | 52 | 60 |
| *Poa pratensis* | 2 | 2 | 2 | 40 | 40 |
| **Average** | **11** | **19** | **26.5** | **44.0** | **50.2** |
| 3. Small Seed Grasses (< 0.3 gm/1000 seeds) | | | | | |
| *Agrostis stolonifera* | 14 | 24 | 26 | 26 | 28 |
| *Koeleria cristata* | 12 | 14 | 16 | 16 | 16 |
| **Average** | **13** | **19** | **21** | **21** | **22** |
| 4. Legume Forbs | | | | | |
| *Astragalus sp* | 8 | 28 | 60 | 80 | 90 |
| *Hedysaum alpinum* | 8 | 44 | 52 | 60 | 72 |
| *Hedysaum mackenzii* | 6 | 30 | 38 | 62 | 68 |
| **Average** | **6.7** | **34** | **50** | **68** | **76.7** |
| 5. Shrubs | | | | | |
| *Elaeagnus commutata* | 0 | 8 | 10 | 16 | 16 |

| | | | | | |
|---|---|---|---|---|---|
| *Juniperus horizontalis* | 0 | 0 | 0 | 0 | 0 |
| *Rosa acicularis* | 0 | 0 | 0 | 2 | 2 |
| **Average** | **0** | **2.6** | **3.3** | **6** | **6** |

[1]Source: Walker *et al.* (1977),
Watson *et al.* (1980).

FIGURE 5 : Germination Rates Expressed As A Percentage Of Seeds That Germinated



It is also possible that many small seeds were simply dormant and that dormancy requirements had not been met by the treatment applied. In particular, small seeds may have a light requirement for germination. In theory, a light requirement prevents germination of small seeds which are buried too deep. In such situations, small seeds would exhaust their food reserves before they reach the surface and become autotrophic. Research by Vogel and Curtis (1978) showed that *Koeleria cristata* may have a light requirement for germination. It would have been useful to have tested the viability of the non-germinated seeds to determine if they were dead or simply dormant.

The relationships between seed size and rate of germination might also be related to the amount of food reserves. Small seeds generally germinate rapidly when conditions are suitable, since they have only minimal amounts of stored food for early embryo growth (Bidwell 1974). Germination was also rapid in both *Poa alpina* populations. Over 30 percent of germinable seed had germinated by the fifth day. The rapid rate of germination of *Poa alpina* may have been an adaptation to the short growing season associated with their high-altitude habitats.

The three legume species had good seed germinability (68-90 percent). Germination was slow initially, and less than 10 percent had germinated after five days. However, after this period germination rates increased and became relatively steady.

Seed germination of the three shrub species was very low. None of the *Juniperus horizontalis* and only 3 percent of the *Rosa acicularis* seeds germinated. *Elaeagnus commutata* had better but still poor germination. It is possible that most of the shrub seed was dormant. Stratification has been recommended for both *E. commutata* and *R. acicularis* (Watson *et al.* 1980). However, it is also po[illegible]ble that the seed was not viable, perhaps because it [illegible]een collected while physiologically immature or was improperly stored.

With the exception of the small grass seeds and *Agropyron riparium*, there was a long period between when the first seed germinated and when the last seed that could germinate had done so. The *A. riparium* was the commercial variety Sodar and likely the characteristic of germinating over a long period of time had been "bred out" of the species in order to facilitate harvesting. However, there is great value in germinating over long time periods. Hillson (1979) suggested that native perennial species exhibit this characteristic so that all of the germinants do not get killed by one disasterous event.

The differences in the success of germination tests among species indicates a need for further research in order to standardize germination requirements, seed handling and storage procedures for all native species of grasses, legumes and shrubs. This research should be population specific, because Harrington (1972) reported differences in longevity of seeds of populations of the same species when stored under identical conditions.

### 5.3 General Plant Development

Although data collected over more years are required, the initial results presented in this report indicate the possibility of rapid establishment of a native, productive and diverse plant community in a harsh mountain environment. Emerged seedlings were observed at the study site four weeks after seeding and had produced approximately 20 percent ground cover by the end of the first growing season. Ground cover reached 30 percent by the end of the second growing season in comparison to 9.5 percent achieved after 25 years of natural succession (Figures 6, 7, 8 and 9). However, this general success should be evaluated in terms of the 80 percent ground cover of the adjacent undisturbed grassland. Cover ranged from a low of 5 percent to a high of 75 percent among the treatment plots.

The percent ground cover produced by the different seed mixtures was statistically equivalent. There was apparently enough species diversity in each mixture to overcome the lack of success of any one species. Mixtures #1 and #2 were both dominated by the *Agropyron* species. In Mixture #3 (the slightly more successful of the three), *Agropyron* sp. was codominant with *Festuca saximontana*.

As stated above, comparisons of percent ground cover among species are not valid. However, general success in establishment can be discussed. At the end of the first

FIGURE 6: Ground Cover At The Study Site Prior To Treatment

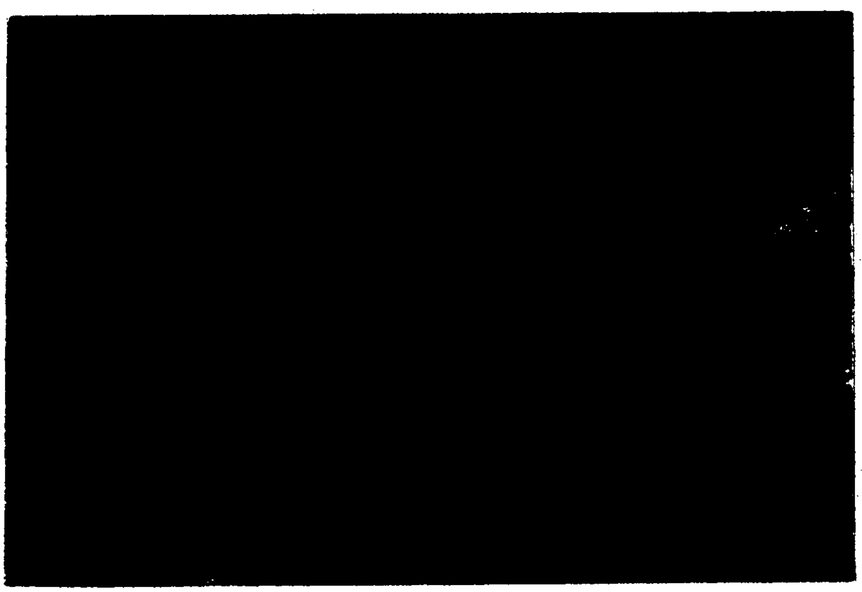


FIGURE 7: Ground Cover After Treatment. Note poor cover on untreated area at right.

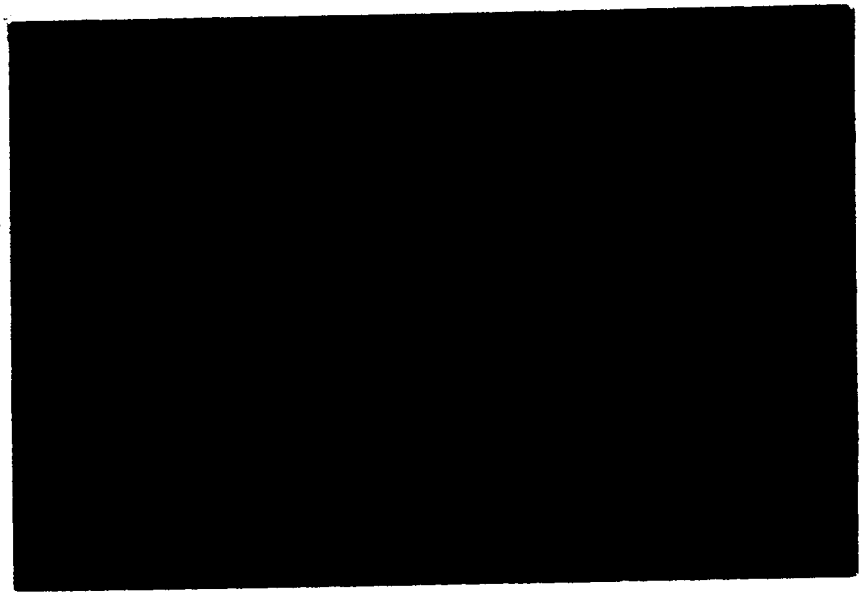


FIGURE 8: Ground Cover At The Study Site Prior To Treatment

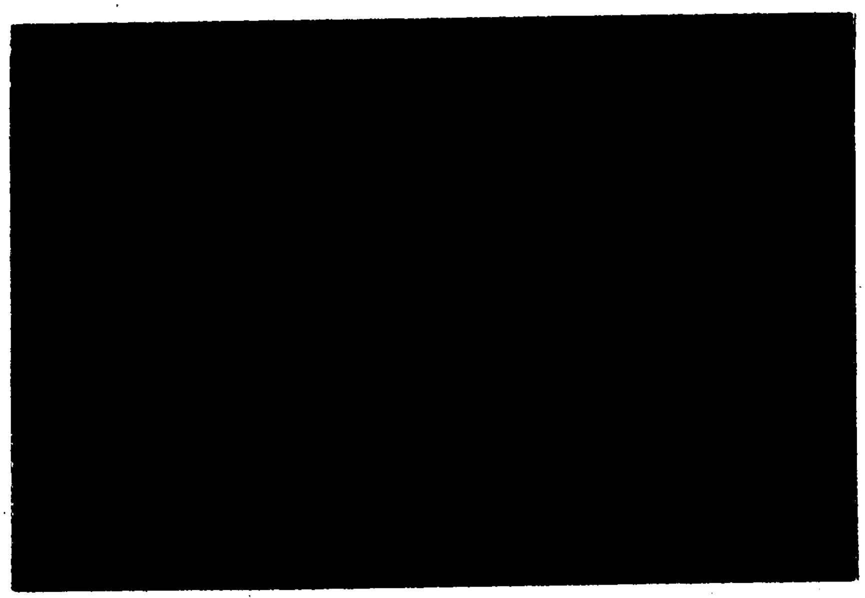


FIGURE 9: Ground Cover After Treatment. Note <u>Agrostis stolonifera</u> inflorescence and poor cover on untreated area at left.

growing season *Agropyron trachycaulum*, *A. riparium*, *A. sp.*, *Poa alpina* (#1 and #2), *Agrostis stolonifera* and *Festuca saximontana* were established in all topdressing treatments. *Koeleria cristata*, *Poa pratensis* and *Elymus innovatus* were the only other species recorded at the site. By the end of the second growing season twelve species had become established at the study site, with *E. innovatus* notably absent (Table 6). *E. innovatus* had presumably been winter-killed.

Two grass species, *Koeleria cristata* and *Agrostis stolonifera*, each produced less than 4 percent cover. Both species had poor results in germination tests. While the lack of light may have influenced germinability of these small-sized seeds in germination tests, broadcasting and packing seeding methods left the seed exposed to light in the field experiments. Consequently, poor seed viability was likely a major contributing factor to their lack of success. However, site characteristics also appeared to have influenced success of establishment. For example, *K. cristata* had been recorded on loamy sand topdressed plots in 1977 but apparently was winter-killed on these plots. Further, Rowell (1979) had poor success with *A. stolonifera* on alkaline, Athabasca Oil Sand tailings and felt that the species prefers acidic soil conditions.

The three legumes were slow to establish and were not recorded until the middle of the second growing season. Klebesadel (1971) also found native legumes to be slow to

Table 6: Percent Ground Cover of Individual Species[1] and Seed Mixtures[2] from Field Experiments

| Seed Mixture 1 | Percent Ground Cover |
|---|---|
| *Agropyron trachycaulum* | 13.91 |
| *Elymus innovatus* | 0 |
| *Poa alpina #1* | 9.27 |
| *Hedysarum mackenzii* | 3.31 |
| *Juniperus horizontalis* | 0 |
| Average | 29.71 |
| **Seed Mixture 2** | |
| *Agropyron riparium* | 13.84 |
| *Koeleria cristata* | 2.89 |
| *Poa pratensis* | 6.59 |
| *Agrostis stolonifera* | 3.51 |
| *Astragalus sp.* | 4.82 |
| *Rosa acicularis* | 0 |
| Average | 30.21 |
| **Seed Mixture 3** | |
| *Agropyron sp.* | 11.25 |
| *Festuca saximontana* | 12.14 |
| *Poa alpina #2* | 6.83 |
| *Hedysarum alpinum* | 4.04 |
| *Elaeagnus commutata* | 0 |
| Average | 31.17 |

[1] As measured September 2-5, 1978.
[2] Averages for the 1978 growing season and include ground cover provided by encroachment of non-seeded species from adjacent sites.

establish and suggested that if the legumes are to provide cover in the first growing season, they must be planted as early in the season as possible. Since seeding was completed at the study site 45 days after the start of the effective growing season, slow establishment was anticipated. Random examination of some of the legumes showed no evidence of nodulation on the roots at the end of the field experiments. However, the plants were still relatively young and nodules may not have begun to form.

None of the shrubs seeded at the site became established. The germination tests showed that these seeds were difficult to germinate and may require some pre-treatment. However, normal seasonal weather patterns meet stratification requirements under natural conditions. The lack of success of the shrubs even in the second growing season indicates that the seed may not have been viable or that pre-treatments other than stratification are required. It is also possible that competition from the grasses had inhibited establishment of the shrubs. The faster germinating and growing grasses would initially dominate the shrubs and limit the amount of moisture, nutrients and light available to them. Lesko *et al.* (1975) and DePuit and Coenenberg (1979) had poor success with seeding of shrubs along with grasses in reclamation trials.

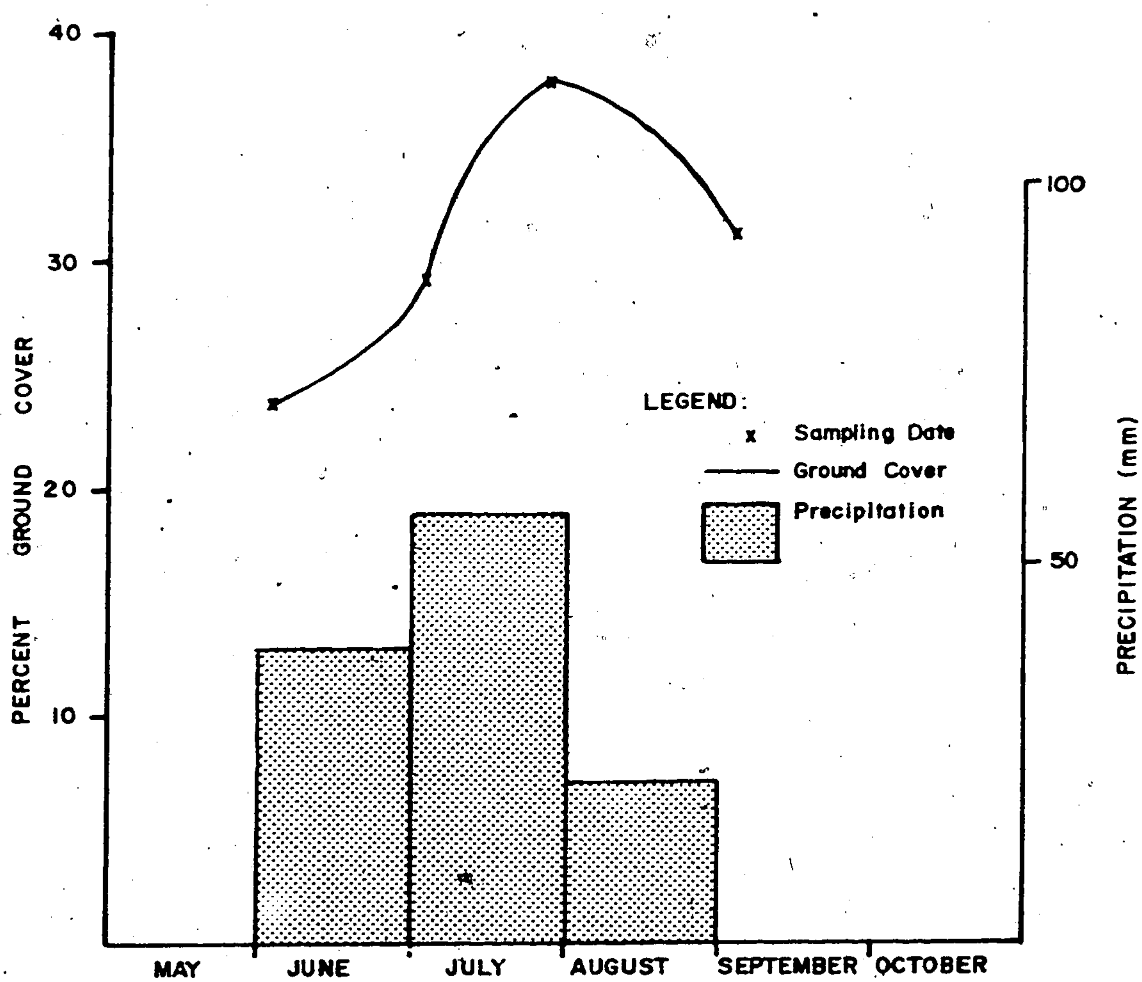
Non-seeded, volunteer species were of little significance in the first growing season and did not contribute more than 1 percent to ground cover. *Taraxacum* *sp.* and *Galium sp.* were the most common volunteer plants on the test plots. In the second season, volunteer species become somewhat more frequent on the study site. *Artemisia sp.* and various unidentified *Compositae* were also noted on several plots. Collectively, volunteer species contributed approximately 3 percent to ground cover by the end of the second growing season. The relatively low ground cover produced by the volunteer species on the prepared and amended seedbeds after two growing seasons may be indicative of the poor natural seed supply in the area. Nevertheless, the invasion of these species on the study area was considered important in achieving increased ground cover and in assessing the effectiveness of the various treatments.

**5.4 Season**

Percent ground cover changed significantly during the 1978 growing season (Table 7).

A comparison of mean values for each sampling date showed that plant cover increased until the end of July at which time cover began to decline (Figure 10). The decrease in ground cover coincides approximately with a decline in precipitation and the start of the period when moisture deficits occur (Stringer 1969, Hettinger 1975). Plant growth declines as the days become shorter and moisture becomes limited. Consequently, the plants lose their succulence and, as grazing continues, plant cover decreases. Erickson (1969)

FIGURE 10: Relationship Between Ground Cover and Precipitation During the 1978 Growing Season



found similar results on study plots on native British Columbia grasslands and Smoliak *et al.* (1975) described this pattern as typical of native grasslands.

Table 7: Comparison of Mean Plant Cover for Each Sampling Period

| Date | Percent Ground Cover[1] |
|---|---|
| June 3-6 | 23.70 c |
| June 28-30 | 28.45 b |
| July 25-27 | 38.07 a |
| September 2-5 | 31.06 b |

[1] Means followed by the same letter are not significantly different at $P \leq 0.01$

## 5.5 Topdressing Treatments

Statistical analyses showed that topdressing treatments significantly affected plant growth (Table 8). Multiple comparisons of treatment means showed that the peat topdressing had no statistically significant effect while loamy sand topdressing produced the least ground cover. Not topdressing the site was the superior treatment.

By examining the major site factors that were potentially limiting revegetation, it was possible to develop explanations regarding the results of topdressing treatments. Other factors which may have influenced the results, such as populations and activities of microorganisms, could not be determined from the data collected.

Table 8: Comparison of Topdressing Treatment Means[1,2]

| Treatment | Percent Ground Cover | Average Weight per Plant (mg) | Average Height per Plant (cm) |
|---|---|---|---|
| Not Topdressed | 34.85 a | 42.11 a | 25.39 a |
| Peat Topdressed | 32.65 a | 34.71 ab | 23.76 ab |
| Loamy Sand Topdressed | 23.60 b | 27.79 b | [illegible].28 b |

[1] Percent ground cover values are from field experiments and weight and height yields are from greenhouse experiments

[2] Means followed by the same letter are not significantly different at $P \leq 0.01$.

### 5.5.1 Soil Moisture

Precipitation in both growing seasons was more than 50 percent above the long term average, and soil moisture deficits were probably of little significance. Consequently, the effect of topdressing on moisture retention and availability would not have been as evident as may occur in normal or drier seasons. The greenhouse experiments, in which moisture was not limited, showed that other factors were largely responsible for the poorer ground cover on both peat and loamy sand topdressing treatments (see Section 5.6).

No tests were conducted to determine the moisture holding characteristics of the topdressing mediums or to monitor their moisture levels in the field experiments. Consequently, the effect of the topdressing treatments on soil moisture can only be surmised from the patterns of plant development. Nevertheless, several significant interpretations can be made.

The plots topdressed with loamy sand were coarser textured than either of the other soil types. They also had the lowest organic matter content. One potential advantage of applying the loamy sand topdressing was to create a relatively gravel-free seedbed. However, after rototilling the site, the gravel that had been extensive on the soil surface was incorporated into the loamy sand. On the plots not topdressed, rototilling brought to the surface the underlying materials that contained less gravel. In a sense, rototilling the plots not topdressed simulated topdressing with indigenous materials. The end result was that the topdressed plots did not contain significantly less gravel than those that were not topdressed. Consequently, it is probable that the addition of loamy sand simply aggravated moisture holding problems.

In mid-summer, when evapotranspirative demands are greatest, the plots topdressed with peat produced the most ground cover (Figure 11). Furthermore, at the beginning of September the plants were still predominantly green on soils topdressed with peat while plants on other treatments had cured. Bidwell (1974) noted that a lack of soil moisture is an important factor initiating dormancy and increased soil moisture relative to the other topdressing treatments may have been at least partially responsible for the delay of dormancy on soils topdressed with peat. Consequently, it is probable that topdressing with peat did at least slightly increase available soil water. However, even in mid-summer the difference in cover between the plot topdressed with peat and those not topdressed were not statistically significant (Table 9). Hernandez (1973) determined that when moisture was adequate, peat topdressed soils were inferior to mineral soil Had drier conditions prevailed throughout the growing season, peat may have proven more beneficial while the loamy sand topdressing may have produced even poorer ground cover.

Below 15 cm in depth, the soils of the peat topdressed plots did not differ in texture or organic content from those that were not topdressed. This indicates that even after tillage, the peat was not incorporated into lower depths. Research by Allison (1973) and Weston (1973) showed that unless the topdressing is effectively incorporated into

FIGURE II : Changes in Ground Cover on Topdressing Treatments During the 1978 Growing Season

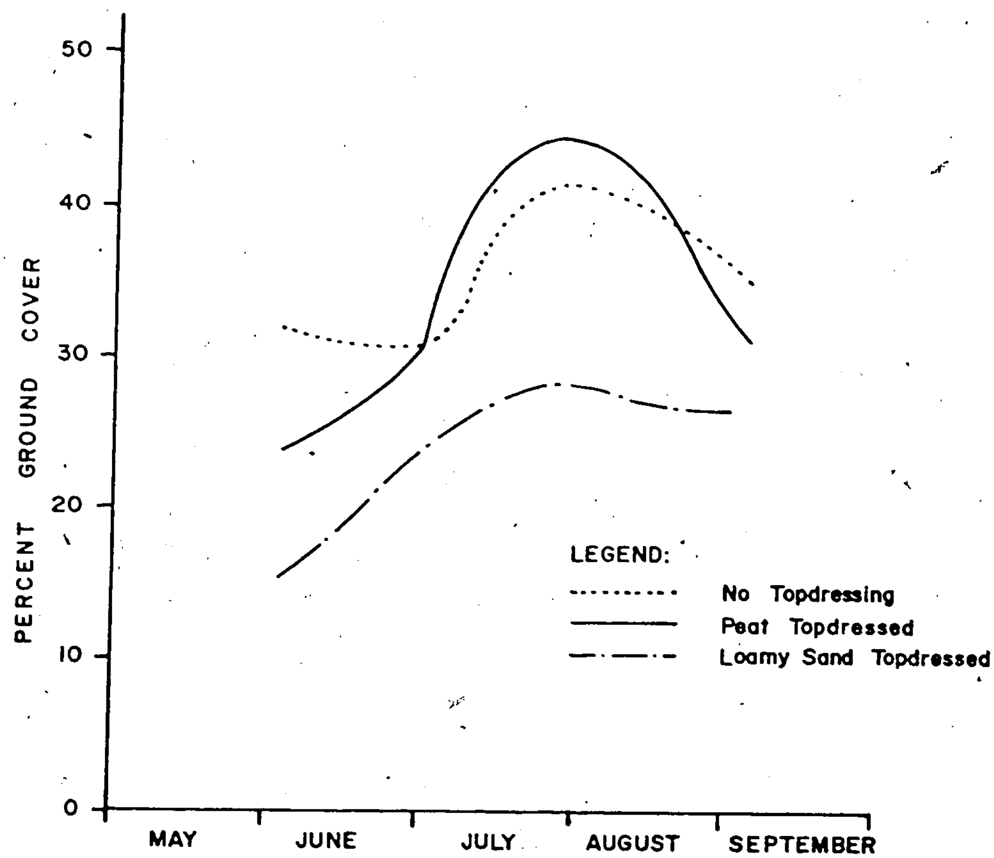


Table 9: Comparison of Topdressing Treatment Means for Each Sampling Period.

| Date | Treatment | Percent Ground Cover[1] | |
|---|---|---|---|
| June 3-6 | Not Topdressed | 31.88 | cd |
| | Peat Topdressed | 24.17 | e |
| | Loamy Sand Topdressed | 15.05 | f |
| June 28-30 | Not Topdressed | 30.68 | cd |
| | Peat Topdressed | 30.89 | cd |
| | Loamy Sand Topdressed | 23.80 | e |
| July 25-27 | Not Topdressed | 41.67 | ab |
| | Peat Topdressed | 44.32 | a |
| | Loamy Sand Topdressed | 28.32 | cd |
| September 2-5 | Not Topdressed | 35.16 | bc |
| | Peat Topdressed | 31.20 | cd |
| | Loamy Sand Topdressed | 26.82 | de |

[1] Means followed by the same letter are not statistically different at $P \leq 0.01$

the underlying seedbed, roots will almost exclusively concentrate in the surficial material. Shallow-rooted plants are more susceptible to periods of drought than deeper-rooted plants. This may explain the dramatic decline of ground cover on peat topdressed plots in the droughty month of August, 1978 (Figure 11). The less dramatic decline in the plots which were not topdressed may indicate deeper-rooted plants. The plots topdressed with loamy sand had the smallest decline which may indicate that the roots were tending to concentrate in the finer-textured subsoils, which have greater moisture holding capacities. The shallow depth to which rototillers can effectively till suggests that another implement, such as a chisel plow, might be more appropriate for incorporating topdressings.

### 5.5.2 Fertility

In the greenhouse environment, soil moisture and temperature were maintained at levels which would not limit plant growth. The uncontrolled factor was soil fertility. In terms of weight and height yield, the soils not topdressed were statistically superior to soils topdressed with loamy sand and superior but statistically equal to soils topdressed with peat (Table 8). Consequently, it appears that the addition of loamy sand or peat topdressings decreased soil fertility.

Soil tests conducted on the two topdressing materials prior to application showed both to be extremely low in available nitrogen and phosphorous (see Appendix C). The peat topdressing was strongly acidic (ph 5.2), low in free lime and had sufficient quantities of sulfur for normal plant growth. The loamy sand topdressing was moderately alkaline (pH 8.0), low in sulfur, had moderate levels of free lime and was low in organic matter. Both soils were non-saline.

In the first year of the field experiments, peat was observed to have better establishment and sustained growth than either of the other topdressing treatments. This may be due largely to a reduction of soil pH and a subsequent increase in nutrient availability when the acidic peat was incorporated into the alkaline soil. The enhanced fertility at the time of seeding can be important as seedlings are generally less able to absorb soil nutrients than mature plants (Bidwell 1974).

In the second growing season, peat generally was slightly inferior to soils not topdressed. Furthermore, in greenhouse experiments using topdressing materials collected from the plots at the end of the second year, soils topdressed with peat produced slightly less biomass. Soil tests conducted on the soil materials collected at the end of the field experiments showed that the soil topdressed with peat had become moderately alkaline (pH 8.0) and levels of free lime were high. Two years of calcareous loess deposition in addition to the high concentration of soil bases in the orginal soil material likely counteracted the acidifying effect of the peat. The fibric peat used in the experiments has a lower CEC than highly decomposed peats and consequently has a lower capacity to buffer the soil from alkalinity. In terms of the availablility of soil nitrogen and potassium which is not related to alkalinity, the soils topdressed with peat were as infertile as those not topdressed. Much of the plant-available nitrogen in the soils topdressed with peat could have been immobilized by soil microorganisms decomposing the organic matter (Brady 1974). Cundell (1977) found that organic amendments to mine tailings resulted in depletion of available nitrogen and subsequent reduction of plant growth two years after application. It was possibly this depletion of available nitrogen that resulted in poorer plant growth on soils topdressed with peat relative to soils not topdressed. This effect can produce negative results for several years as decomposition of the large mass of organic matter continues. While sulfur levels were higher than those in the soils not topdressed, the negative results achieved in the greenhouse experiments indicate that sulfur was not a limiting factor.

Establishment on control plots and plots topdressed with loamy sand was equal in the first year of the field experiments. Upon application, the soils topdressed with loamy sand were similar in terms of soil pH and available nitrogen and phosphorus. Available potassium was considerably lower in the soils topdressed with loamy sand, however, this did not appear to affect first year growth.

In the second year of the field experiments and in the greenhouse experiments, the loamy sand topdressing was statistically inferior to soils not topdressed. Soil tests showed that the loamy sand had increased in alkalinity. Its pH was 8.5 in comparison to 8.2 for the soils not topdressed. The coarse loamy sand soils would have a lower CEC than the finer textured sandy loam on the plots not topdressed. Consequently, the soils topdressed with loamy sand would be more susceptible to increases in alkalinity caused by the calcareous loess deposition. It is probable that this high level of alkalinity relative to the soil not topdressed further reduced availability of some of the nutrients and caused the negative responses associated with the application of loamy sand topdressings.

### 5.5.3 Soil Temperature

Percent ground cover was signficantly lower in the spring (June 3-6) on soils topdressed with peat than on soils that were not topdressed (Figure 11 and Table 9). At the end of July, plants were more mature on both the loamy sand soils and those that were not topdressed than they were on the soils topdressed with peat. Seed production was just beginning on the plots topdressed with peat while seed production was much more advanced on both other treatments. In comparison, plants in greenhouse experiments, where temperature was controlled, produced seed one week earlier on soils topdressed with peat than plants on other topdressing treatments and the plants matured at the same time. This suggests that there was a delay in the development of plants on soils topdressed with peat in the field experiments and that this delay was probably caused by low soil temperatures in the spring.

Peat has superior moisture retention capabilities compared to loamy sand or to the soils not topdressed. It is probable that the peat would have retained more moisture and remained moist longer than either of the other treatments. The enhanced soil moisture levels may have significantly reduced mean soil temperature by readily providing moisture for evaporation. Russell (1973) found that moist soils will use almost all absorbed radiation to evaporate water and concluded that this can be very damaging in regions with cold winters and hot summers where crops require warm soils to germinate. Hausenbuiller (1972) found that the most frequent limitation to plant development results from excessive wetness in the spring which causes low soil temperatures. Low soil temperatures retard seed germination and early growth and can cause late spring frost damage. The cooler and moister-than-normal weather conditions that prevailed during both the 1977 and 1978 growing seasons likely contributed to the problem of low temperatures in soil topdressed with peat. If an early winter had occurred in either year, the effect of delayed plant development may have been catastrophic to the vegetation on the plots topdressed with peat.

The addition of peat may have produced a beneficial effect on soil temperature in mid-summer. At moisture tensions which limit evaporation (-5 to -15 bars), peat topdressing can cause an increase in minimum and a decrease in maximum soil temperatures (Russell 1973). The reduction of extremes of soil temperatures results from enhanced transfer of radiant energy to and from lower soil depths by means of soil water. Water is an excellent thermal conductor relative to the predominant air medium of the coarser loamy sands or sandy loams of the other topdressing treatments. Therefore, moderately moist peat topdressings can reduce the potential for lethally high soil temperatures as well as extend the growing season later into the fall by increasing minimum temperature. The reduction of soil extremes may be partially responsible for the superior ground cover on plots topdressed with peat in late July (Figure 11).

Had very dry conditions prevailed through both growing seasons, the peat topdressing could have produced lethally high soil temperatures. As the peat becomes very dry (<-15 bars) the transfer of absorbed thermal energy becomes restricted. Because peat has a lower albedo, dry peat topdressing can cause higher maximum soil temperatures than would occur on the soil topdressed with loam sand on those that were not topdressed. It is not probable that such dry conditions would occur in the early spring, so an early warming of soils and subsequently early initiation of plant growth in future years is unlikely.

### 5.5.4 Grazing

While recognizing the significant implications of grazing activities, quantitative assessments of the effect of grazing were beyond the objectives of this study. However, while not excessive, grazing did appear to be somewhat more intensive on the plots topdressed with peat, particularly from mid-summer to the end of the growing season. There are two explanations for this apparent preference.

As discussed above, the peat topdressing likely retained more available soil water in mid-growing season than either of the other topdressing treatments. The plants growing on the plots topdressed with peat would likely maintain more water during this period than plants on other treatments. Consequently, the plants on the peat topdressing may have been more succulent and palatable.

Secondly, there was an apparent delay in the development and maturation of the plants on the soil topdressed with peat. In the late summer, plants on the plots topdressed with peat were still green, while plants on the other plots had cured. Again, these plants would likely be more succulent than those on the soils topdressed with loamy sand or those not topdressed.

The apparent preference for grazing on plots topdressed with peat may be at least partially responsible for the decline in ground cover relative to the other topdressing treatments from mid-summer to the end of the growing season.

(Figure 11). Further, the selective nature of grazing may account, in part, for the success or lack of success of particular species on the soils topdressed with peat.

**5.5.5 Species Responses**

Statistical analyses determined that there were significant interactions between topdressing and species in both the field and greenhouse experiments. However, the results of the two experiments differed (Tables 10 and 11). In the field experiments, species which produced significantly greater ground cover on the plots that were not topdressed were: *Agrostis stolonifera*, *Festuca saximontana*, *Koeleria cristata*, and *Poa alpina* #1. Field experiments indicated that peat topdressing was more suitable than other topdressings for: *Agropyron trachycaulum*, *Poa alpina* #2 and *Poa pratensis*. In contrast, the greenhouse experiments showed that *Agropyron riparium* and *A. trachycaulum* grew taller on soils that were not topdressed. *Agrostis stolonifera* and *Poa pratensis* grew equally well on soils topdressed with peat and soils not topdressed. Further, *Poa alpina* #1 showed no preference for any topdressing treatment. The differences in the results of the two experiments indicate that soil moisture and temperature, which were controlled in the greenhouse, significantly affected the success of a species in the field. Other factors, such as competition between species and grazing, probably also contributed to the differences.

Table 10: Comparison of Topdressing Treatment Means for Each Species in Field Experiments

| Species | Treatment | Percent Ground Cover[1] | |
|---|---|---|---|
| *Junipererus horizontalis* | Not Topdressed | 0 | q |
| | Peat Topdressed | 0 | q |
| | Loamy Sand Topdressed | 0 | q |
| *Agropyron riparium* | Not Topdressed | 12.50 | efg |
| | Peat Topdressed | 14.22 | bcde |
| | Loamy Sand Topdressed | 14.81 | abcde |
| *Agropyron trachycaulum* | Not Topdressed | 13.53 | cdef |
| | Peat Topdressed | 16.63 | ab |
| | Loamy Sand Topdressed | 11.56 | fg |
| *Agropyron sp.* | Not Topdressed | 11.69 | fg |
| | Peat Topdressed | 11.13 | fgh |
| | Loamy Sand Topdressed | 10.94 | ghi |
| *Agrostis stolonifera* | Not Topdressed | 7.00 | jkl |
| | Peat Topdressed | 0 | q |
| | Loamy Sand Topdressed | 3.53 | mnop |
| *Elymus innovatus* | Not Topdressed | 0 | q |
| | Peat Topdressed | 0 | q |
| | Loamy Sand Topdressed | 0 | q |
| *Festuca saximontana* | Not Topdressed | 17.16 | a |
| | Peat Topdressed | 8.38 | jk |
| | Loamy Sand Topdressed | 10.88 | ghi |
| *Koeleria cristata* | Not Topdressed | 8.66 | ij |
| | Peat Topdressed | 0 | q |
| | Loamy Sand Topdressed | 0 | q |
| *Poa alpina #1* | Not Topdressed | 15.09 | abdc |

| | | | |
|---|---|---|---|
| | Peat Topdressed | 3.75 | mnop |
| | Loamy Sand Topdressed | 8.97 | hij |
| *Poa alpina #2* | Not Topdressed | 2.41 | opq |
| | Peat Topdressed | 15.41 | abc |
| | Loamy Sand Topdressed | 2.69 | mop |
| *Poa pratensis* | Not Topdressed | 1.78 | pq |
| | Peat Topdressed | 12.84 | defg |
| | Loamy Sand Topdressed | 5.16 | lmn |
| *Rosa acicularis* | Not Topdressed | 0 | q |
| | Peat Topdressed | 0 | q |
| | Loamy Sand Topdressed | 0 | q |
| *Astragalus sp.* | Not Topdressed | 6.06 | klm |
| | Peat Topdressed | 4.31 | mnop |
| | Loamy Sand Topdressed | 4.09 | mnop |
| *Hedysarum alpinum* | Not Topdressed | 4.25 | mnop |
| | Peat Topdressed | 5.03 | lmno |
| | Loamy Sand Topdressed | 2.84 | nop |
| *Hedysarum mackenzii* | Not Topdressed | 3.78 | mnop |
| | Peat Topdressed | 3.19 | nop |
| | Loamy Sand Topdressed | 2.97 | nop |
| *Elaeagnus commutata* | Not Topdressed | 0 | q |
| | Peat Topdressed | 0 | q |
| | Loamy Sand Topdressed | 0 | q |

[1] Means followed by the same letter are not statistically different at P≤0.01

Table 11: Comparison of Topdressing Treatment Means for Each Species Used in Greenhouse Experiments

| Species | Treatment | Average Weight Per Plant (mg)[1] | Average Height Per Plant (cm)[2] |
|---|---|---|---|
| *Agrostis stolonifera* | Not Topdressed | 33.18 | 23.58 d |
| | Peat Topdressed | 34.26 | 26.02 cd |
| | Loamy Sand Topdressed | 16.52 | 17.92 e |
| *Agropyron riparian* | Not Topdressed | 63.40 | 38.36 a |
| | Peat Topdressed | 49.76 | 33.28 b |
| | Loamy Sand Topdressed | 33.40 | 33.10 b |
| *Agropyron trachycaulum* | Not Topdressed | 87.54 | 38.40 a |
| | Peat Topdressed | 61.94 | 34.36 b |
| | Loamy Sand Topdressed | 76.02 | 28.68 c |
| *Poa alpina #1* | Not Topdressed | 9.46 | 7.38 g |
| | Peat Topdressed | 9.28 | 6.58 g |
| | Loamy Sand Topdressed | 5.60 | 5.64 g |
| *Poa pratensis* | Not Topdressed | 16.98 | 19.22 e |
| | Peat Topdressed | 18.30 | 18.56 e |
| | Loamy Sand Topdressed | 7.44 | 11.08 f |

1 F value insignificant at $P \leq 0.01$
2 Means followed by the same letter are not significantly different at $P \leq 0.01$

The remaining species showed no statistically significant preferences for any topdressing treatment. This was due to total failure in the case of the three shrubs and *Elymus innovatus* or because of uniform success among topdressings as with the three legumes, *Agropyron sp.* and *A. riparium* in the field experiments. No species showed a statistically significant preference for the soil topdressed with loamy sand.

The experiments were not designed to enable a ranking of species suitability for revegetating the study site. Those species that performed better on a particular topdressing treatment are not necessarily better adapted to that topdressing than are other species. Rather, they are simply better adapted to that topdressing treatment than to any other topdressing treatment tested. While not necessarily statistically valid, some trends in the relationship between species success and topdressing treatments warrant discussion.

The dominant species in Seed Mixture #1, *Agropyron trachycaulum*, produced the greatest cover on soils topdressed with peat in the field experiments. As discussed above, it appears as though the soils topdressed with peat were at least somewhat moister than other topdressing treatments. In greenhouse experiments, where moisture was definitely not limiting, *A. trachycaulum* produced as much biomass on soils not topdressed as on soils topdressed with peat. This indicates that even though precipitation was well above long term averages, the population of *A. trachycaulum* used in the experiments responded positively to enhanced moisture. Consequently, the long term success of this population if drier, more normal climatic conditions prevail is suspect. *Poa alpina* #1 produced more ground cover on soils not topdressed than on soils topdressed with peat in both the field and greenhouse experiments. As discussed above, the soils not topdressed were apparently more fertile than the other topdressing treatments. These results suggest that during relatively moist growing seasons, *P. alpina* #1 preferred more fertile soils compared to those that are more moist. In the field experiments, this population of *P. alpina* performed better on soils topdressed with loamy sand than those topdressed with peat. This may be a result of greater grazing pressures on the soils topdressed with peat or to increased competition from other plants. The short growth form of *P. alpina* would make it unable to compete for light with the taller *A. trachycaulum*, which achieved its best growth on the soils topdressed with peat. The only other species in Seed Mixture #1 which become established at the site was *Hedysarum mackenzii*. It achieved its best cover on the plots that were not topdressed and second best on plots topdressed with peat. These results suggest that the population used in the experiments was not sensitive to competition and that it preferred a more fertile site to one that might be somewhat moister.

Seed Mixture #2 was dominated by *Agropyron riparium* which produced slightly greater cover on plots topdressed with loamy sand than with peat. Cover was poorest on those plots not topdressed. The opposite was true in the greenhouse experiments. However, in the field, three of the other species in the seed mixture produced their greatest cover on the plots not topdressed. These results may indicate that while *A. riparium* was not an aggressive competitor, it was tolerant to low fertility and droughty soils. *Koeleria cristata* only became established on those plots not topdressed. There is not sufficient information to determine why this occurred. However, as discussed in the next section, the fertility of the site was apparently not an important factor. *Poa pratensis* performed significantly better on soils topdressed with peat than either of the other treatments. However, in the greenhouse, where moisture was not limited, *P. pratensis* grew as well on soils not topdressed as on those topdressed with peat. This indicates that even in periods with above-normal precipitation, *P. pratensis* responded positively to the higher moisture levels that may have been available in the soils topdressed with peat. Consequently, the population of *P. pratensis* used in the experiments did not appear to be drought tolerant and its long term success is questionable. *Agrostis stolonifera* did not establish in the field on soils topdressed with peat, while in the greenhouse experiments it produced its best growth on these soils. No explanation for these contradictory results can be formulated from the data. The legume species in Seed Mixture #2, *Astragalus sp.*, responded similarly to *Hedysarum mackenzii*, achieving its best cover on soils not topdressed and its poorest cover on those topdressed with loamy sand. It appears as though in moist seasons, this population also preferred a more fertile site to one that was somewhat moister.

Two species were predominant in Seed Mixture #3, *Agropyron sp.* and *Festuca saximontana*. *Agropyron sp.* showed no preference for any topdressing treatment. The population apparently has a wide ecological amplitude. *F. saximontana* produced its greatest ground cover on the plots not topdressed and poorest on those topdressed with peat. This population was apparently quite drought tolerant. Its poor performance on the soils topdressed with peat may be due to greater grazing pressures on these plots or to increased competition from *Poa alpina* #2 and *Hedysarum alpinum*, which both achieved their best cover on this treatment. *P. alpina* #2 did poorly on both other topdressing treatments, suggesting that the population was not drought tolerant. *H. alpinum* performed well on the plots not topdressed and consequently may be somewhat more drought tolerant than *P. alpina* #2. However, it did appear less tolerant to drought than either of the other legumes.

The amount of cover provided by non-seeded species appeared to be related to the type of topdressing. The plots topdressed with loamy sand had more volunteer plants than the plots topdressed with peat. The plots not topdressed had the fewest volunteer plants. While it appeared as though the amount of cover of non-seeded species was inversely related to percent ground cover from seeded species, an examination of fertilized and non-fertilized plots, as discussed below, indicated that this was not the situation. It may be that the two topdressings contained more seed than was present in the soils not topdressed. The poor natural seed source at the study site would not provide as much seed as may have been available at the source of the topdressings. The greater amount of volunteer plants on the plots topdressed with loamy sand relative to the plots topdressed with peat may be due to either a greater amount of seeds or a greater proportion of seeds of species adapted to this xeric environment.

### 5.5.6 Long Term Potentials

Two years of data are insufficient to accurately determine the long term success of the topdressing treatments. Variations in weather from year to year alter the conditions that may favour a particular topdressing treatment. Nevertheless, some predictions can be made on the basis of data collected.

The potential for the peat topdressings to benefit revegetation by enhancing moisture retention should have been manifested in the first two growing seasons. Enhanced moisture retention in the shallow topdressing would have been of most benefit to the germinating seedling and the juvenile plant. After two growing seasons the plants should have established a considerable portion of their root biomass below the 10 cm of peat enriched soil. Consequently, enhanced moisture in this surface material should be of less benefit in future years. If the roots do tend to concentrate in the peat topdressing, the peat may produce a negative effect by encouraging shallow rooted plants that are susceptible to even short periods of drought. A shallow rooting habit was postulated as an explanation for the sharp decline in ground cover on the soils topdressed with peat in the droughty month of August 1978. A much greater depth of peat, such that deeper roots would benefit from improved moisture, may be necessary to enhance revegetation in the long term. Research by Logan (1978) and Simard (1968) indicated that somewhere between 25 and 66 cm may be a minimum depth at which peat must be applied to improve soil moisture and plant growth in the long term.

While several chemical changes will likely occur in the peat, it is not anticipated that overall fertility will improve significantly. As the fibric peat decomposes, more humus will form and humus has a greater CEC than fibric peat (Brady 1974). Consequently, the ability of peat to buffer changes in pH and to retain available nutrients may increase. Decomposition of peat can also release immobilized elemental sulfur and sulfates which can ultimately reduce soil pH and increase fertility (Tisdale and Nelson 1975).

However, loess deposition at the site appears to be nearly continuous so that reductions in pH would likely be short lived. Furthermore, the nutrient content of peat has been proven to be very low (Massey 1972, Logan 1978) and available nitrogen has been found to be largely immobolized by microorganisms as they decompose the peat (Cundell 1977).

Soil temperature characteristics of peat may also affect revegetation success in the long term. A delay in early spring growth on soils topdressed with peat was postulated to have resulted from cool spring soil temperatures. This may cause delayed maturity of the plants which could produce occasional sharp declines in ground cover due to extensive winter kill. In extremely droughty years, peat topdressings could result in lethally high soil temperatures.

Consequently, it is probable that the shallow topdressing with peat will not benefit revegetation in the long term and may produce an overall negative effect. The rate of decomposition will determine the length of time that peat topdressings will affect plant cover. If decomposition of organic matter exceeds detrital input, then the peat eventually will be depleted. However, if the rate of detrital input equals or exceeds the rate of decomposition, the effect of peat will persist.

The long-term effectiveness of loamy sand topdressing will be determined largely by its ability to retain soil moisture. A general reduction of plant cover relative to the other topdressing treatments is anticipated to occur as precipitation in the growing season declines to near the 30 year average level. The fertility of the soil will probably not change significantly. There are almost no organic sources of nutrients in the topdressing to enhance fertility. Furthermore, the alkalinity of the loamy sand topdressing will likely not change since the solubility of lime limits pH to near the present level of 8.5 (Brady 1974).

Consequently, plant cover on plots not topdressed will likely remain the same or increase relative to other topdressing treatments. Any improvement in cover on soils not topdressec e :ive to those topdressed with peat would be a result of shallow rooting of plants or adverse soil temperatures on peat soils. An increase in cover relative to soils topdressed with loamy sand would be due to the better moisture holding capacity of the original soils. As with loamy sand, fertility will not likely change significantly since soil pH is already near the maximum associated with non-saline soils and the soil is low in organic nutrient sources.

### 5.6 Fertilizer Treatment

The application of fertilizer at the time of seeding significantly improved percent ground cover during both growing seasons (Table 12). The fertilized plots averaged about 6.5 percent greater plant cover on all samping dates.

Greenhouse experiments showed that plant weight and height were also improved by applying fertilizer. Consequently, fertilization proved to be an effective means of improving revegetation.

Table 12: Comparison of Fertilizer Treatment Means[1,2]

| Treatment | Percent Ground Cover | Average Weight Per Plant (mg) | Average Height Per Plant (cm) |
|---|---|---|---|
| Unfertilized | 26.92 | 15.42 | 16.73 |
| Fertilized | 33.73 | 54.32 | 28.90 |

[1] Percent ground cover values are from field experiments and weight and height yields are from greenhouse experiments

[2] All means are significantly different at $P \leq 0.01$

In both the field and greenhouse experiments, the application of fertilizer inhibited germination and inital growth rates. One week after seeding in the greenhouse, 102 seeds had germinated and emerged in the unfertilized pots in comparison to 21 emergents in the fertilizer pots. The fertilized plants were also shorter than the unfertilized plants for the first four weeks of the experiments (Figures 12, 14, 16, 18 and 20). Similarly, in the field experiments, emergence was superior on the unfertilized plots four weeks

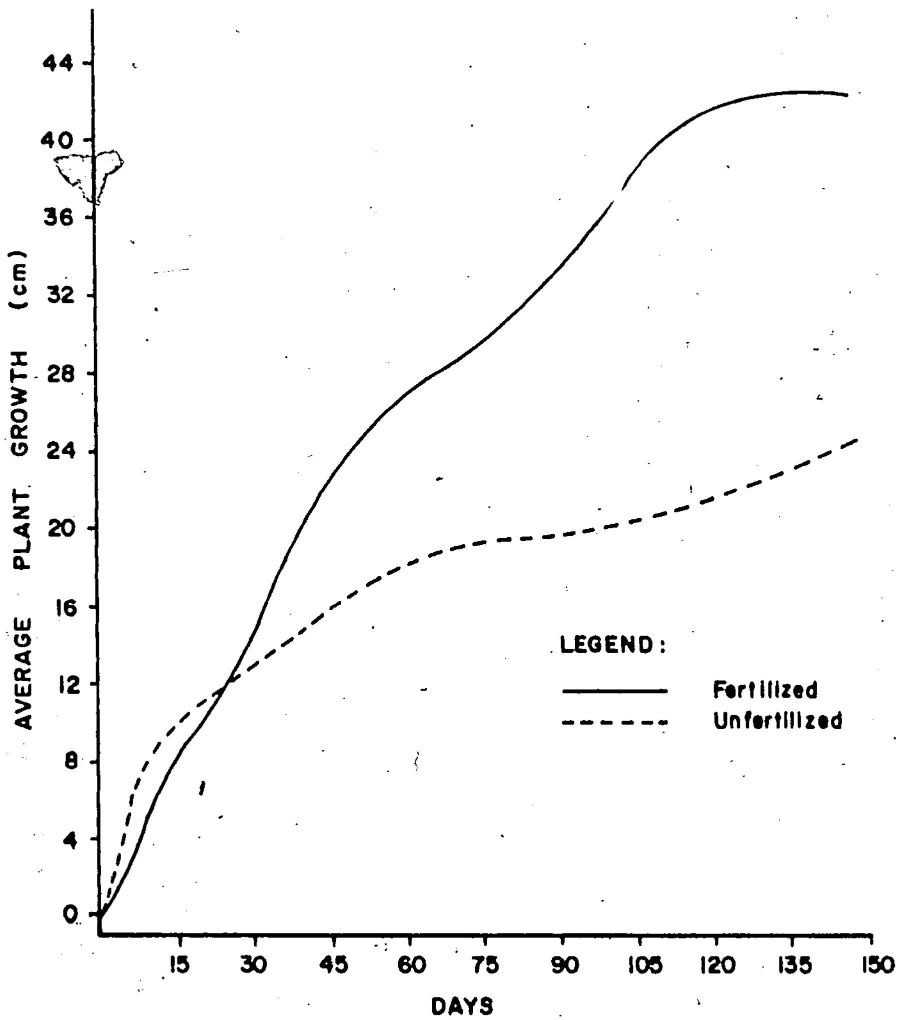



FIGURE 12: Effect of Fertilizer Treatment on Height Growth of _Agropyron riparium_ in Greenhouse Experiments

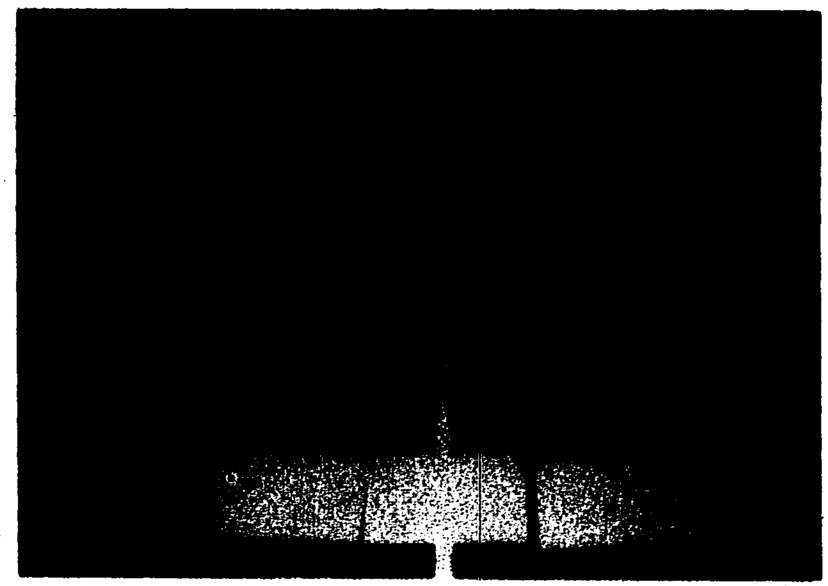


FIGURE 13: Comparison of _Agropyron riparium_ Plants Grown Under Different Topdressing and Fertilizer Treatments in Greenhouse Experiments

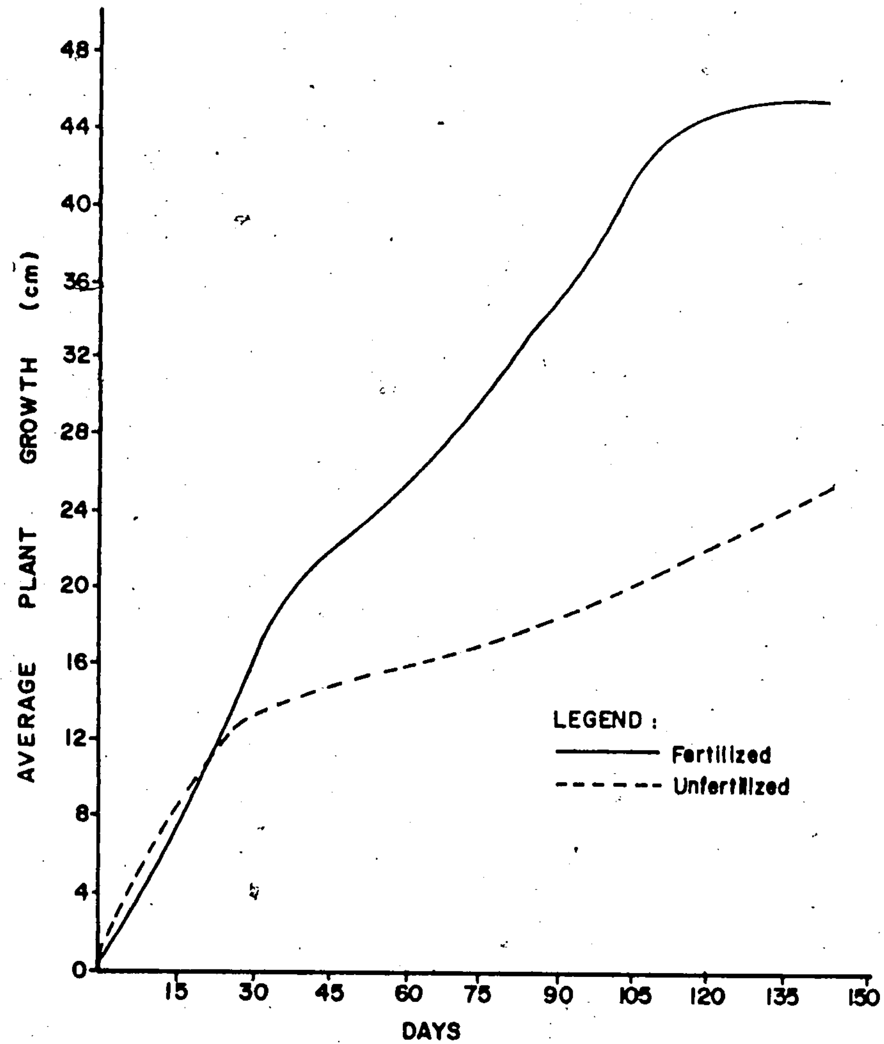



FIGURE 14: Effect of Fertilizer Treatment on Height Growth of _Agropyron trachycaulum_ in Greenhouse Experiments

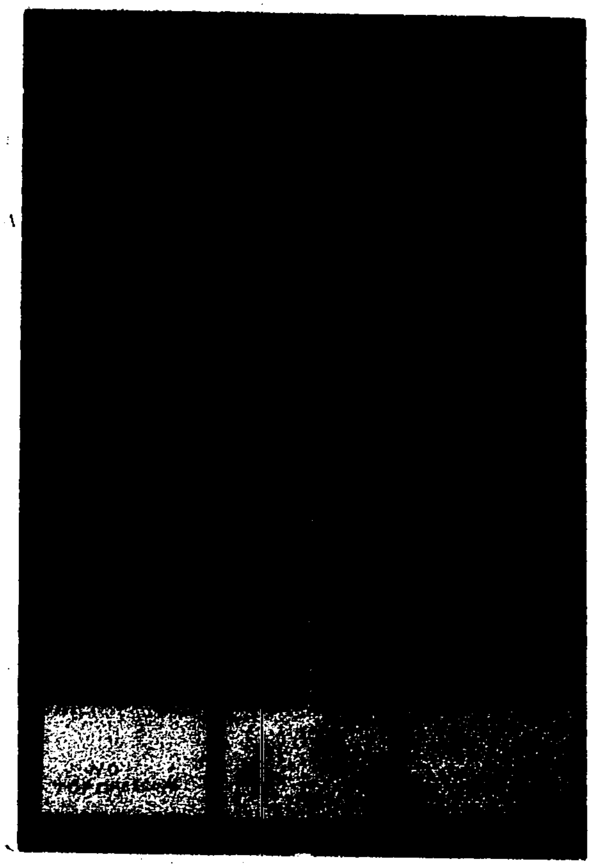


FIGURE 15: Comparison of _Agropyron trachycaulum_ Plants Grown Under Different Topdressing and Fertilizer Treatments in Greenhouse Experiments

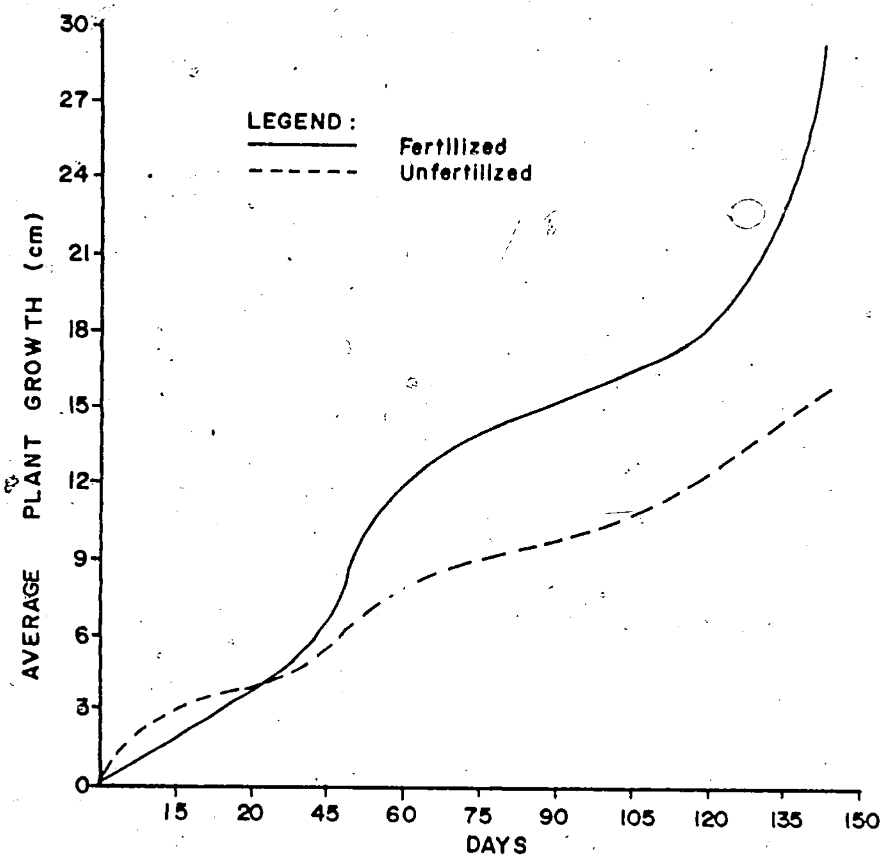



FIGURE 16: Effect of Fertilizer Treatment on Height Growth of Agrostis stolonifera in Greenhouse Experiments

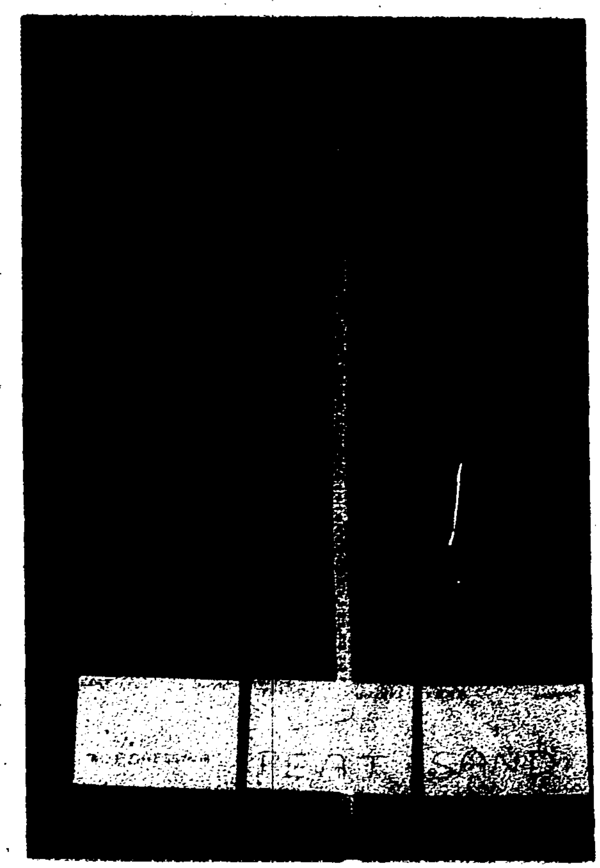


FIGURE 17: Comparison of Agrostis stolonifera Plants Grown Under Different Top-dressing and Fertilizer Treatments in Greenhouse Experiments

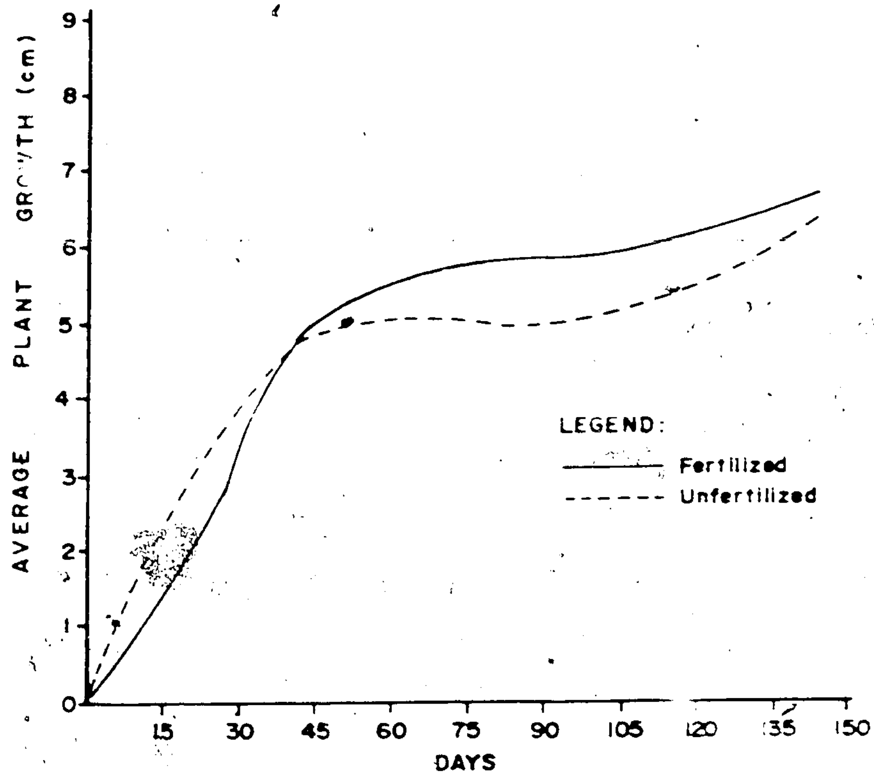



FIGURE 18: Effect of Fertilizer Treatment on Height Growth of Poa alpina in Greenhouse Experiments

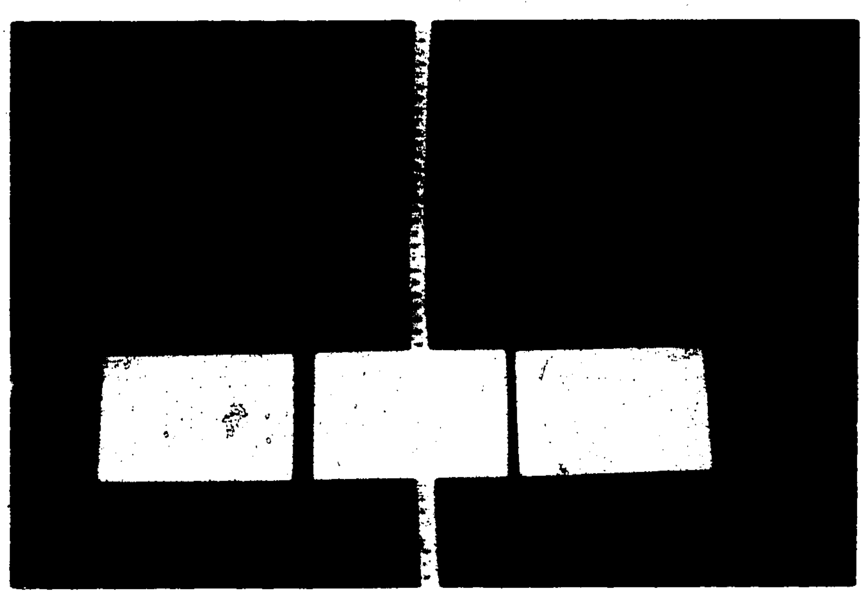


FIGURE 19: Comparison of Poa alpina Plants Grown Under Different Topdressing and Fertilizer Treatments in Greenhouse Experiments

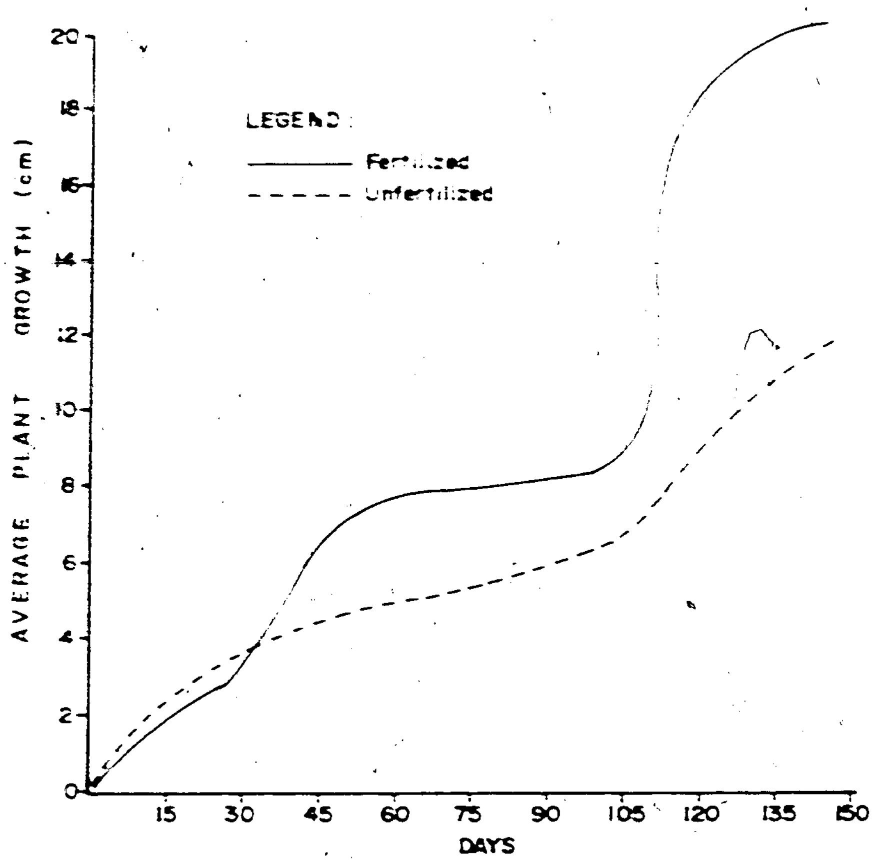



FIGURE 20: Effect of Fertilizer Treatment on Height Growth of Poa pratensis in Greenhouse Experiments

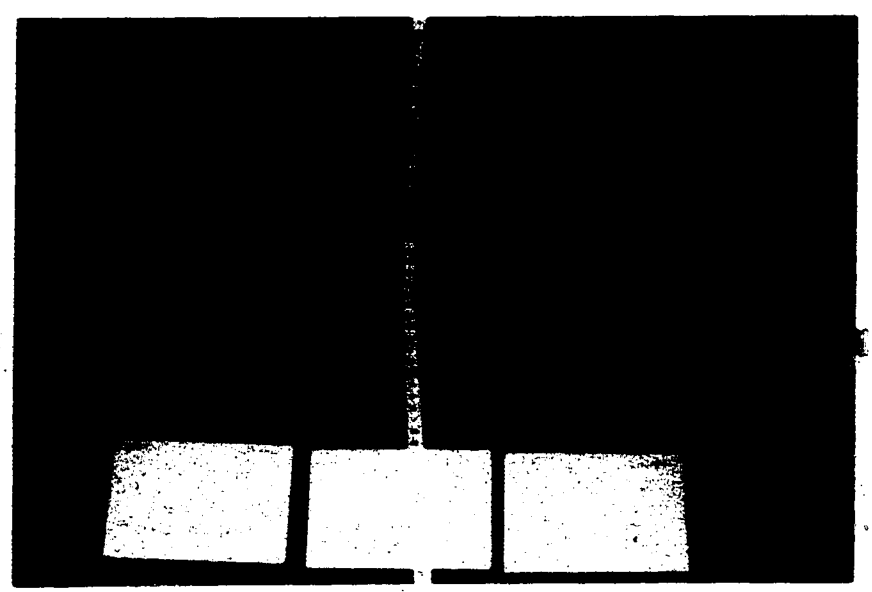


FIGURE 21: Comparison of Poa pratensis Plants Grown Under Different Topdressing and Fertilizer Treatments in Greenhouse Experiments

after seeding.

The negative effect of fertilization was, however, short-lived. Five weeks after seeding in the greenhouse and nine weeks after seeding in the field, plants were developing better on the fertilized treatments. Further, the fertilizer did not seem to affect the number of seeds that ultimately germinated and emerged.

The delay in germination was likely a result of the osmotic effect of fertilizer salts, particularly nitrogen salts. As the salts pass into solution, they decrease osmotic potential in the soil (Tisdale and Nelson 1975). Consequently, the movement of soil water to the seed and the ability of the seed to absorb water are impaired. However, moisture was apparently abundant enough even in the field experiments to overcome the effect of the fertilizer salts. In a drier season, the fertilizer treatment may have ultimately reduced germination, although Bauer *et al.* (1978) found that only at rates of 1120 kg of nitrogen per hectare were grasses seriously affected on semi-arid grasslands.

Bidwell (1974) reported that excessive amounts of nitrogen can result in the formation of plants with thin cell walls and weak stems. This renders the plant more susceptible to disease or climatic stresses. However, a comparison of the weight of plants per centimetre of length showed that the fertilized plants weighed 1.87 mg/cm in comparison to 0.92 mg/cm for unfertilized plants. The fertilized plants must have been thicker and likely stronger than those not fertilized.

Bidwell (1974) also suggested that excessive soil fertility, particularly with respect to nitrogen, can delay seed production and crop maturity. However, in both the field and greenhouse experiments seed production and maturity were enhanced by fertilizer application. Seed was abundant on the fertilized plots by June 27-30, 1978, while it was almost absent on the unfertilized plots. No seed was produced by the plants in the unfertilized pots in the greenhouse, but 31 plants in fertilized pots had seed. At the end of both experiments the fertilized plants had cured to the same extent as the unfertilized plants, indicating no delay in maturity.

Studies by Ziemkiewicz (1979) and Bidwell (1974), indicate that fertilization, particularly with nitrogen, decreases the root/shoot ratio. Ziemkiewicz (1979) found that on montane grasslands, fertilization stimulated shoot production at a time when soil moisture began to limi shoot biomass. Any additional shoot production died and was added to the detrital pool. Ultimately, this left the roots with less biomass when roots were most important. In the greenhouse experiments, shoot production was significantly, greater on the fertilized treatments; however, root biomass could not be measured. Consequently, the validity of Ziemkiewicz's (1979) and Bidwell's (1974) studies cannot be determined from the data collected. Further, above average moisture in both growing seasons, reduced the possibility to observe any moisture stresses imposed by a decrease in root/shoot ratio. As discussed below, since the effect of fertilizer application on soil fertility was apparently negligible after two growing seasons, root/shoot ratios would likely return to normal and no long-term impacts are implied.

### 5.6.1 Soil Tests

The results of the soil tests taken from both the fertilized and unfertilized halves of all topdressing treatments at the end of the second growing season do not explain the beneficial results of the fertilization (see Appendix C). All three fertilized plots were as deficient in nitrogen and phosphorus as the plots not fertilized. Further, the application of the acidifying fertilizer did not reduce soil pH. Sulfur levels were, however, slightly higher on the fertilized plots. Takyi and Russell (1980) also found no evidence of increased fertility two years after application of fertilizer (80-40-80 kg/ha) on mine tailings at Cadomin, Alberta.

The soil test results were only for depths to 30 cm. While this is the zone where root development is most concentrated, roots can develop well below 30 cm. Consequently, any beneficial effect of fertilizer on soils below the sampled depth could not be detected.

From the data collected, it is not possible to determine quantitatively the fate of the applied nutrients.

However, there are several possible explanations for the loss of nutrients from the upper 30 cm of the soil. Obviously, some of the available nitrogen was absorbed and synthesized by the vegetation. Rowell (1979) found that once plant root systems are established, up to 160 kg of nitrogen per hectare can be absorbed by plants in a single year and estimated that 42 percent of 180 kg/ha of nitrogen was taken up by seeded grasses in one growing season on Athabasca Oil Sand tailings north of Fort McMurray, Alberta. The greater ground cover and taller plants observed on the fertilized plots provide evidence that some of the applied nitrogen was utilized in the manner.

A significant amount of nitrogen may have been lost to direct volatization of ammonia gas. Ammonium salts in an aqueous alkaline medium can react as follows (Tisdale and Nelson 1975):

$$NH_4^+ + OH^- \Longleftrightarrow NH_4OH$$
$$NH_4OH \Longleftrightarrow H_2O + NH_3(g)$$

Free ammonia gas escapes. Losses from the reaction are enhanced by high soil temperature and rapid evaporation. The conditions conducive to high soil temperature and evaporation existed during both growing seasons in which the fertilizer was applied. Losses as great as 36 percent of applied ammonium have been reported by Tisdale and Nelson

(1975) on soils containing only 0.25 percent $CaCO_3$. Further, Russell (1973) suggested that, under extreme circumstances, volatization of ammonia can conceivably cause the loss of all ammonium nitrogen present in the soil. While the enhanced growth on the fertilized plots indicates that some nitrogen was taken up by the plants, volatization likely contributed significantly to the loss of nitrogen. The loss of ammonia gas was probably aggravated by placing the fertilizer on the soil surface where the diffusion of ammonia to the atmosphere is unrestricted (Brady 1974). Incorporating the nitrogen into the soil would have reduced the potential for volatile losses.

Some of the applied nitrogen was probably leached below the 30 cm depth from which samples were collected. Although ammonium nitrogen is not highly mobile, the conversion of ammonium to nitrate nitrogen will occur most rapidly in well-drained, well-aerated, warm soils with a pH near 8.5 (Tisdale and Nelson 1975). These conditions exist at the study site. The nitrate ion is highly mobile and easily leached out of the soil. The above-average precipitation in both years may have encouraged the process.

As discussed in the previous section, the decomposition of organic matter by microorganisms can result in a depletion of available nitrogen. This may have been of some significance on the peat topdressed plots, however, it does not explain the lack of available nitrogen on the fertilized plots topdressed with loamy sand or those not topdressed.

Under certain circumstances, nitrogen can be lost through ammonium fixation or denitrification. However, ammonium fixation is of significance only in soils rich in negatively charged clay or organic matter (Tisdale and Nelson 1975). None of the treatment soils had large amounts of clay and only the soils topdressed with peat had significant amounts of organic matter. While some ammonium fixation could have occurred in the soils topdressed with peat, Tisdale and Nelson (1975) believed that ammonium fixation is generally of little significance. Denitrification is an anaerobic process usually induced by waterlogging of soils (Tisdale and Nelson 1975). The high permeability of the coarse-textured soils on the plots, including those under the soils topdressed with peat, would prevent such conditions from occurring.

Phosphorus was almost completely unavailable two growing seasons after application of more than 150 kg/ha in a water soluble form. A considerable amount of phosphorus may have been absorbed and synthesized by the plants. Rowell (1979) estimated that between 15 and 31 percent of applied phosphorus (150 kg/ha) was taken up plants in revegetation trials on Athabasca Oil Sand tailings. The remaining phosphorus was likely subject to fixation. Russell (1973) found that ammonium-phosphorus fertilizers dissolve easily and that the phosphorus can form chemical precipitates with low solubilities. In alkaline soil, the activity of calcium is generally high and the most common fate of phosphorous is the formation of calcium diphosphate precipitates, which plants are unable to absorb (Tisdale and Nelson 1975). Furthermore, the high levels of free lime in the soil may have resulted in the precipitation of phosphorus on the surface of these particles, the end result of which is the formation of insoluble salts (Tisdale and Nelson 1975). The problems of alkalinity and free lime in the soil are compounded by apparently continuous calcareous loess deposition. Banding the fertilizer below the soil surface may have proved beneficial.

Studies by Fox and Kamprath (1971) have shown that phosphorus in sandy soils and those rich in peat can be subject to losses through leaching. However, leaching losses are of significance only when these soils are acidic and lack aluminum and iron compounds, not when the soils are highly alkaline such as at the study site.

The addition of sulfate sulfur appears to have increased the level of sulfur in the soil even two growing seasons after application. In all topdressing treatments, the level of sulfur was higher on the fertilized plots. Sulfur levels were highest in the soil topdressed with peat. Since sulfur levels were also higher on the unfertilized peat plots than on the fertilized plots of either other topdressing treatment, it appears as though elemental sulfur and sulfides, which are common in peat soils contributed to the higher levels (Tisdale and Nelson 1975).

Sulfate losses from soils are generally due to leaching (Tisdale and Nelson 1975). Because of its anionic nature and the high solubility of its common salts, such as calcium sulfate, leaching losses of sulfates are generally high (Tisdale and Nelson 1975). The somewhat higher level of sulfates in the subsoil samples of both coarse-textured topdressings indicates that leaching was of some significance on these soils. Sulfate levels were not higher in the subsoils of plots topdressed with peat. This indicates that leaching was not as extensive on soils topdressed with peat, which generally agrees with research by Chao *et al.* (1962), in which organic matter was shown to enhance retention of sulfates.

The addition of ammonium sulfate fertilizer did not significantly affect soil pH after two years. The volatization of ammonia would have reduced the amount of ammonium available for nitrification, an acid forming process. Furthermore, the leached sulfate salts could not contribute to the acidification of the soil. Consequently, while the amount of acidifying fertilizer that was applied to the plots was high, the amount that was available for acidifying the soil may have been relatively low.

The slightly lower pH on the fertilized plots topdressed with peat relative to those not fertilized may have been due to two factors. First, the peat topdressing at the time of application was acidic in nature. The acidic condition would restrict volatization of nitrogen and allow a greater amount of ammonium to nitrify. Secondly, the soils topdressed with peat may have been able to retain more of the applied sulfates. Nevertheless, the effect of applying acidifying fertilizer was probably significantly negated by the large amount of soil bases at the site and by deposition of calcareous loess between application and soil sampling.

### 5.6.2 Grazing

Grazing activities were observed to be somewhat more intensive on the fertilized plots. It is likely that the fertilized plants were more nutrient-rich and palatable than the unfertilized plants (Maduran 1979). In the long term, these activites may gradually reduce the fertility of the site by removing some of the organic material available for nutrient cycling. Furthermore, any improvement to the physical characteristics or microclimate of the site associated with the greater plant biomass of the fertilized plots eventually may be negated. Ultimately, selective grazing on fertilized plots may offset any beneficial effects resulting from fertilization. Further, by selectively consuming the more palatable species on the fertilized plots, grazing animals can reduce the diversity of the community.

### 5.6.3 Species Responses

The application of fertilizer significantly affected the success of most species in both the field and greenhouse experiments (Tables 13 and 14). In the field experiments, most species that became established at the site benefited from fertilization. The exceptions were *Agropyron riparium*, *Koeleria cristata* and the three legume species. In the greenhouse experiments, *Poa alpina* #1 did not respond to fertilization, while all other species did. Those species that did not benefit from fertilization are not necessarily better adapted to the natural low fertility of the study site. Other factors, such as increased competition, the method or rate of fertilizer application and increased grazing pressures may have influe[illegible] the results.

A decrease in the diversity of the plant community has been reported as a result of fertilization of seeded native grasses (Mains 1977, DePuit and Coenenberg 1979). This decrease in diversity was a result of dominance of one or two species under high fertility. However, in the field experiments, the percent ground cover was not significantly lower for any species when fertilized. Rather, diversity was somewhat increased as a result of the ground cover provided by *Agrostis stolonifera* on fertilized plots. The species was almost completely unsuccessful on unfertilized plots. Tayki and Russell (1980) reported similar results with the greatest diversity of native species being achieved at levels of fertilization intermediate to no fertilizer or very high levels of fertilizer.

Research by DePuit and Coenenberg (1979) and Rowell (1979) showed that nitrogen fertilization significantly

Table 13: Comparison of Fertilizer Treatment Means for Each Species in Field Experiments

| Species | Treatment | Percent Ground Cover[1] | |
|---|---|---|---|
| *Juniperus horizontalis* | Unfertilized | 0 | n |
| | Fertilized | 0 | n |
| *Agropyron riparium* | Unfertilized | 13.38 | bc |
| | Fertilized | 14.31 | ab |
| *Agropyron trachycaulum* | Unfertilized | 11.90 | cd |
| | Fertilized | 15.92 | a |
| *Agropyron sp.* | Unfertilized | 9.06 | ef |
| | Fertilized | 13.44 | bc |
| *Agrostis stolonifera* | Unfertilized | 0.44 | m |
| | Fertilized | 6.58 | gh |
| *Elymus innovatus* | Unfertilized | 0 | n |
| | Fertilized | 0 | n |
| *Festuca saximontana* | Unfertilized | 11.10 | d |
| | Fertilized | 13.17 | bc |
| *Koeleria cristata* | Unfertilized | 3.10 | kl |
| | Fertilized | 2.67 | l |
| *Poa alpina #1* | Unfertilized | 8.13 | fg |
| | Fertilized | 10.42 | de |
| *Poa alpina #2* | Unfertilized | 4.92 | hijk |
| | Fertilized | 8.73 | ef |
| *Poa pratensis* | Unfertilized | 5.52 | hi |
| | Fertilized | 7.67 | fg |

| | | | |
|---|---|---|---|
| *Rosa acicularis* | Unfertilized | 0 | n |
| | Fertilized | 0 | n |
| *Astragalus sp.* | Unfertilized | 4.21 | ijkl |
| | Fertilized | 5.44 | hij |
| *Hedysarum alpinum* | Unfertilized | 3.13 | kl |
| | Fertilized | 4.96 | hijk |
| *Hedysarum mackenzii* | Unfertilized | 3.42 | jkl |
| | Fertilized | 3.21 | kl |
| *Elaeagnus commutata* | Unfertilized | 0 | n |
| | Fertilized | 0 | n |

[1] Means followed by the same letter are not statistically different at $P \leq 0.01$.

Table 14: Comparison of Fertilizer Treatment Means for Each Species Used in Greenhouse Experiments[1]

| Species | Treatment | Average Weight Per Plant (mg) | Average Weight Per Plant (cm) |
|---|---|---|---|
| *Agrostis stolonifera* | Unfertilized | 15.09 de | 15.67 e |
| | Fertilized | 40.88 c | 29.35 b |
| *Agropyron riparium* | Unfertilized | 20.47 de | 25.00 c |
| | Fertilized | 77.23 b | 44.83 a |
| *Agropyron trachycaulum* | Unfertilized | 27.17 cd | 24.75 c |
| | Fertilized | 23.16 a | 42.88 a |
| *Poa alpina #1* | Unfertilized | 7.5[illegible] e | 6.[illegible] g |
| | Fertilized | 8.72 e | 6.67 g |
| *Poa pratensis* | Unfertilized | 6.85 e | 11.81 f |
| | Fertilized | 21.63 de | 20.76 d |

[1] Means followed by the same letter are not significantly different at $P \le 0.01$.

decreased legume establishment. In contrast, Regier (1973) determined that ammonium nitrate applied at 135 kg/ha increased the establishment and growth of alfalfa and concluded that the nitrogen benefited the legume at the juvenile stage prior to nodulation. In the field experiments, the application of fertilizer did not significantly affect establishment of the legumes. Furthermore no effect on nodulation of legumes was evident, since no nodules were observed on any of the sampled legumes, including those on unfertilized plots. This lack of response was probably due to the legumes having become established in the second growing season when soil analysis indicated that the nitrogen fertilizer was no longer available in the surface 30 cm of the soil. However, it is also possible that any negative effects of nitrogen application were offset by beneficial effects of enhanced phosphorous and sulfate availability.

More plants of non-seeded species were observed on the fertilized plots than on unfertilized plots. It appears as though the invasion of these plants benefited more from increased fertility than it was adversely affected by increased competition. These results imply that plant cover may have been improved by fertilizing the site even without seeding.

### 5.6.4 Long Term Potentials

The long term effects of the fertilizer application are difficult to assess. Other than those nutrients that may have been leached to rooting depths below 30 cm, none of the applied fertilizer was available for plant absorption by the end of the second growing season. Research by Gates (1962) and Younkin and Friesen (1976) found that while fertilization improved initial seedling establishment, the effect was diminished or non-existent after two growing seasons. However, there was no significant decrease in plant cover on the fertilized plots relative to the unfertilized plots throughout the second season. While these data are too limited to be conclusive, it is possible that a more productive plant-nutrient cycle had been established that would support more ground cover than could exist on the unfertilized areas. The increased plant biomass on the fertilized plots meant that much of the fertilizer had been immobilized as organic matter. The rate of decomposition of this increment in organic matter, and subsequent release of plant available nutrients, appears to have been rapid enough to sustain the improvement in ground cover in the second growing season. The application of fertilizer may also produce a long-term improvement in the physical characteristics of the soil as well as an amelioration of the microclimate of the site. Physical characteristics, such as moisture holding capacity, would be improved as a result of the increased organic biomass in the soil. An amelioration of soil temperature, decreased wind speeds and increased ability to trap and retain water would be provided by the taller plants and greater ground cover on the fertilized plots. Furthermore, even two growing seasons after application, the fertilized plots produced more seed than the unfertilized plots. The production of seed has important implications with respect to maintaining cover on the site in the long term as well as colonizing areas with lesser ground cover. Consequently, although soil test results do not support the theory, the beneficial effects of fertilization may persist for several years.

### 5.7 Topdressing and Fertilizing

Statistical analyses determined that the combined effect of topdressing and fertilizing significantly affected percent ground cover in the field and the height of plants in the greenhouse. While there appeared to be large differences in weight yields, these were determined to be statistically insignificant. The lack of significance in weight yield probably was due to a smaller population size than for the other respondant variables (Table 15, Figures 13, 15, 17, 19, 21, 22, 23 and 24).

The unfertilized soils topdressed with loamy sand produced the poorest results in both field and greenhouse experiments. The unfertilized soils that were not topdressed were superior but statistically equal to the unfertilized soils topdressed with peat. In greenhouse experiments,

Table 15. Comparisons of Means of Combined Topdressing and Fertilizer Treatments[1]

| Treatments | | Percent Ground Cover | Average Weight Per Plant (mg)[2] | Average Height Per Plant (cm) |
|---|---|---|---|---|
| Not Topdressed | Unfertilized | 31.75 bc | 26.02 | 22.11 c |
| Not Topdressed | Fertilized | 37.94 a | 58.20 | 28.65 ab |
| Peat Topdressed | Unfertilized | 30.83 c | 13.44 | 16.94 d |
| Peat Topdressed | Fertilized | 34.46 ab | 55.98 | 30.58 a |
| Loamy Sand Topdressed | Unfertilized | 18.19 d | 6.78 | 11.12 e |
| Loamy Sand Topdressed | Fertilized | 28.78 c | 48.79 | 27.45 b |

[1] Means followed by the same letter are not significantly different at $P<0.01$

[2] The effect of fertilization on weight yields was not significant at $P<0.01$

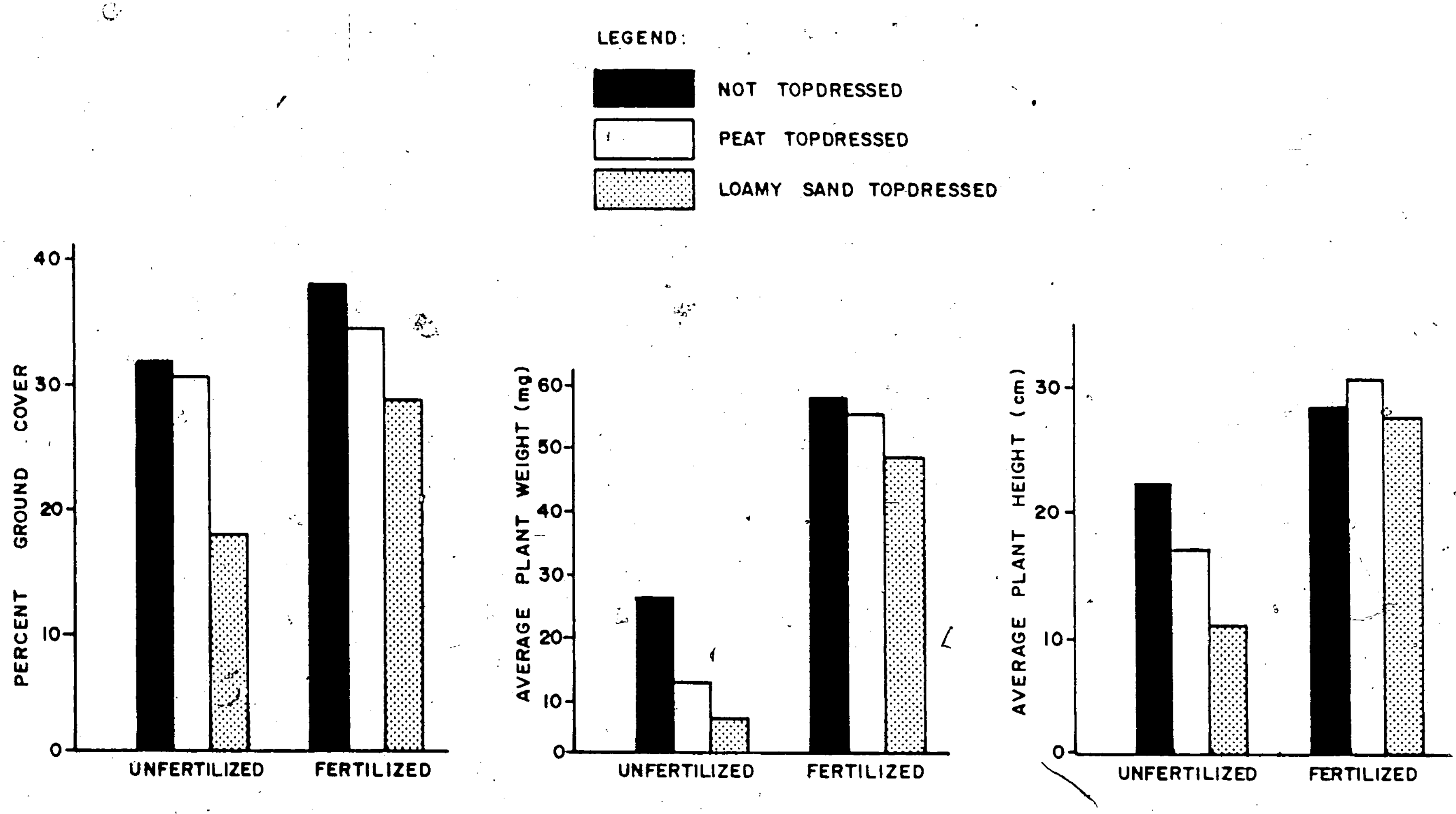



FIGURE 22: Effect of Topdressing and Fertilizer Treatments on Ground Cover in Field Experiments and Plant Weight and Height in Greenhouse Experiments

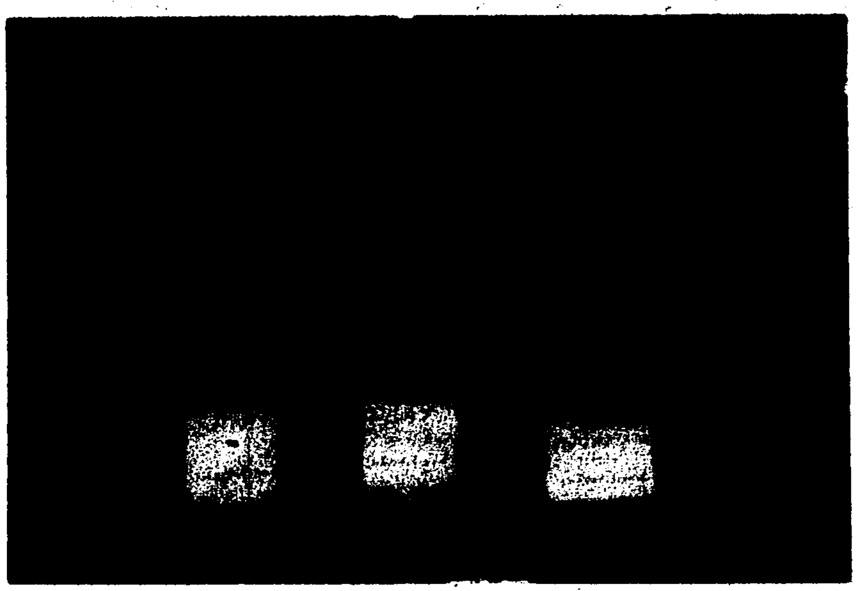


FIGURE 23: Comparisons of Plant Growth on Topdressing Treatments on Unfertilized Soils

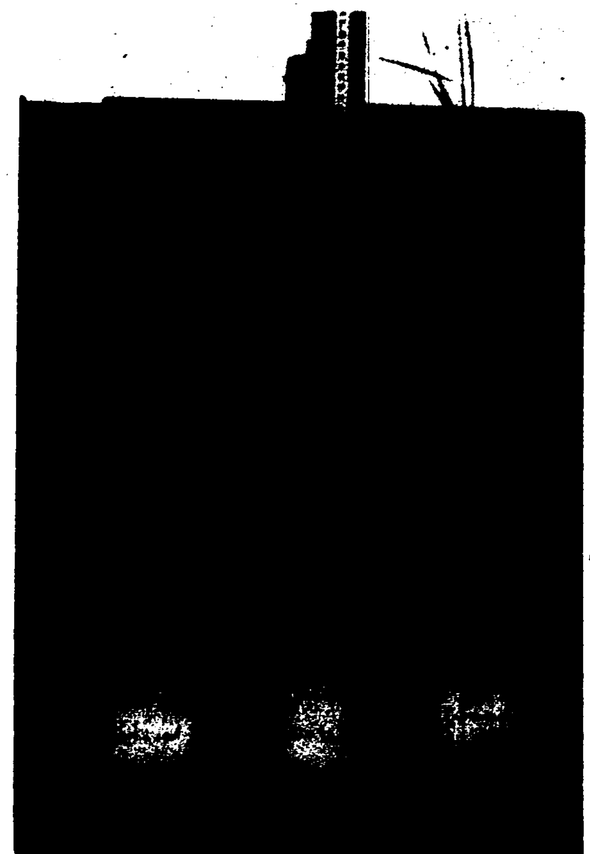


FIGURE 24: Comparisons of Plant Growth on Topdressing Treatments on Fertilized Soils

nitrogen deficiency symptoms (chlorosis of young and old leaves) appeared five weeks after seeding on unfertilized soils topdressed with loamy sand, after six weeks on unfertilized soils topdressed with peat and after nine weeks on unfertilized soils not topdressed. Since soil moisture and soil temperature were not limiting factors in the greenhouse experiments, the results indicate that the differences in responses were related to differences in the inherent fertility of the soils.

Even when fertilized, the same general trends were evident. The fertilized soils topdressed with loamy sand produced poorer results than either of the other fertilized topdressing treatments in both field and greenhouse experiments. The fertilized soils that were not topdressed produced more ground cover in the field and the plants weighed more in greenhouse experiments than other treatments. The fertilized soils topdressed with peat, however, produced taller plants and more seed in greenhouse experiments. It is not possible to determine the reason for the differences in height and weight results from the data collected. Furthermore, the two treatments were not statistically different in either experiment.

There are several reasons why the trends established on unfertilized soils in the greenhouse persisted even when fertilized. It is possible that due to volatization of ammonia and phosphorus fixation that, even at the high rate of application, fertilization did not overcome differences in inherent nitrogen and phosphorus deficiencies. Other nutrients, such as magnesium, iron, managanese, cobalt or boron, may have been most deficient in loamy sand topdressing. Soil tests were not conducted for these elements, so the validity of this statement cannot be determined. A further explanation may be that the general tilth of the soils not topdressed favoured grass production over those topdressed with peat or loamy sand. However, since all soils were predominantly structureless and rooting depth was restricted by the depth of the pots, differences in tilth would likely not be pronounced in greenhouse experiments.

Fertilization had the greatest beneficial effect on soils topdressed with loamy sand. Ground cover increased 58 percent, average plant weight 620 percent and height 147 percent over yields achieved on unfertilized soils topdressed with loamy sand. In comparison, ground cover on fertilized soils not topdressed increased 19 percent, weight 124 percent and height 30 percent over yields on unfertilized soils. The dramatic response of soils topdressed with loamy sand to fertilization is another indication of the low inherent fertility of these soils. Although in the field experiments, fertilization produced the largest increase in ground cover on soils topdressed with loamy sand, the fertilized loamy sand soils still produced less ground cover than the unfertilized soils of other topdressing treatments. The coarse texture of the loamy sand soil is not conducive to retention of moisture and it is probable that even during the relatively moist growing season, available soil water was ultimately more limited in soils topdressed with loamy sand than were nutrients. Consequently, the full beneficial effects of increased fertility could not be realized in the field. In the greenhouse, moisture was not limited and the fertilized soils topdressed with loamy sand outperformed the unfertilized soils of the other treatments. Bauer *et al.* (1978) found similar results in revegetation experiments on semi-arid grasslands and concluded that moisture is often more limited than nutrients on coarse soils.

In greenhouse experiments, the response to fertilization of soils topdressed with peat was greater than that of soils not topdressed, which indicates that the peat was originally less fertile. However, in field experiments peat did not respond as well to fertilization as the soils not topdressed. The difference in the results may be attributable to the pH of the soils topdressed with peat at the time of application. In the greenhouse, fertilizer was applied to peat that had become alkaline. Through nitrification and release of sulfates, the fertilizer may have lowered pH, thus reducing nutrient deficiencies that were induced by the alkaline conditions. In contrast, the peat topdressing was probably still acidic when fertilizer was applied in the field. A reduction in pH from application of acidifying fertilizer would not benefit soil fertility under acidic conditions to the same degree as it would under alkaline conditions.

Collectively, these data indicate that the fertility of the soil generally was more important than moisture-holding capability or other physical traits. The topdressing treatments that demonstrated greater inherent fertility in greenhouse experiments generally were the most successful in the field. Had drier, more normal conditions prevailed, the results may have been different and mositure-holding capability may have proved more significant than fertility.

## 5.8 Seeding Methods

The seeding methods used in the field experiments did not affect overall percent ground cover. Statistical analyses determined for the entire 1978 growing season and for the last three sampling periods, that the differences in percent ground cover achieved by the four seeding methods were insignificant. In the first growing season, differences in the establishment of plants were observed, and statistically significant differences were calculated for the spring sampling period (June 3-6) in the second growing season (Table 16). However, the effect of the treatments had diminished by the end of June, and it appears that the encroachment of established vegetation, both seeded and unseeded, onto poorly vegetated sites eventually reduced differences in initial establishment. Furthermore, seeding methods did not affect establishment among species. This contradicts results achieved by Plummer *et al.* (1955), DePuit and Coenenberg (1979) and Sadasivaiah and Weijer (1980). All species, regardless of seed size, responded similarly to a given method of seeding.

Table 16: Comparison of Means of Seeding Methods

| Seeding Method | Percent Ground Cover (June 3-6, 1978)[1] | Percent Ground Cover (1978 Average)[2] |
|---|---|---|
| Rake | 25.76 a | 32.00 |
| Broadcast | 25.14 ab | 30.85 |
| Pack | 23.13 b | 29.32 |
| Mulch | 20.76 c | 29.11 |

[1] Means followed by same letter are not significantly different at $P \leq 0.01$

[2] Treatment was not significant at $P \leq 0.01$

The effects of seeding methods were at least partially negated by favourable growing conditions in both growing seasons. Weather was conducive to the establishment of vegetation regardless of seeding method. Improvements to the seedbed from a particular seeding method would not have been as evident under these conditions as they may have been under harsher conditions. Nevertheless, some discussion regarding the effectiveness of seeding method treatments is warranted.

Raking proved to be the best overall seeding method. Theoretically, the main beneficial effect of raking is the prevention of seed desiccation (Johnston and Smoliak 1977). However, the above-average precipitation and lower-than-normal temperatures would minimize the potential for desiccation from any seeding method. Furthermore, rolling and mulching also reduce seed desiccation, but were inferior to broadcast seeding for which desiccation is a common cause of failure. Burying the seed by raking may have reduced the amount of seed blown off the site or consumed by animals. However, broadcast seeding was the method that offered the least protection to the seed and proved to be better than mulching or rolling. Consequently, it appears that seed desiccation and removal of seed by wind or animals were not important factors.

The main effect of raking the seed into the seedbed appears to have been related to better placement and retention of fertilizer. Raking the seed and fertilizer into the seedbed would have reduced the amount of seed-fertilizer contact. The detrimental effects that fertilizer can exert on osmotic pressure and soil moisture availability would be partially overcome by mir -ing contact. Furthermore, by burying fertilizer, the ation of ammonium would likely have been inhi soil particles above the fertilizer physically restrict the diffusion of ammonia to the atmosphere (Brady 1974). Consequently, more nitrogen would be retained in the soils that were raked than those where the fertilizer was left on the surface. Table 17 shows a significant improvement in ground cover on raked and mulched plots when fertilized. A much smaller improvement was evident on treatments where the fertilizer was left on the surface.

Further evidence of enhanced nitrogen retention was provided in comparisons of seeding method and topdressing treatments. Raking the seed into the seedbed was the superior method of seeding on soils topdressed with peat and the soils topdressed with loamy sand (Table 18). Greenhouse experiments had indicated that these topdressings were less fertile than the soils not topdressed and enhanced retention of nitrogen would have been more beneficial on these soils with lower fertility.

Broadcast seeding proved to be the second best seeding method overall. On unfertilized plots and those not topdressed, broadcasting was the best method; and had the system of fertilization been altered, broadcasting the seed may have proven most successful. No explanation can be provided for the success of broadcast seeding on these plots. Raking the seed may have placed some seed at an inappropriate depth. However, burying seed is usually more detrimental to species with small seeds, and the correlation between species and seeding method was not significant.

Packing the seed into the seedbed produced less ground cover than simply leaving the seed on the seedbed surface. Poor retention of fertilizer does not explain the negative

Table [illegible]: Comparison of Means of Combined Fertilizer and Seeding Method Treatments

| Fertilizer Treatment | Seeding Method | Percent Ground Cover June 3-6, 1978 | Percent Ground Cover 1978 Average |
|---|---|---|---|
| Unfertilized | Rake | [illegible] | [illegible] |
| | Broadcast | [illegible] bc | [illegible] |
| | Pack | [illegible] | [illegible] |
| | Mulch | [illegible] c | [illegible] |
| Fertilized | Rake | [illegible] a | [illegible] |
| | Broadcast | [illegible] b | [illegible] |
| | Pack | [illegible] b | [illegible] |
| | Mulch | [illegible] b | [illegible] |

[1] Means followed by same letter are not significantly different at $P \leq 0.0$[illegible]

[2] Overall treatment means were not significant at $P \leq 0.01$

Table [illegible] Comparison of Means of Combined Topdressing and Seeding Method Treatments

| Topdressing | Seeding Method | Percent Ground Cover June 3-6, 1978 | Percent Ground Cover 1978 average |
|---|---|---|---|
| Not Topdressed | Rake | [illegible].46 bc | 35.42 |
| | Broadcast | 36.46 a | 36.46 |
| | Pack | 32.29 ab | 35.[illegible] |
| | Mulch | 27.29 cd | 32.2[illegible] |
| Topdressed | Rake | [illegible].21 bc | 35.26 |
| | Broadcast | [illegible].75 c | 32.6[illegible] |
| | Pack | 23.33 de | [illegible].25 |
| | Mulch | [illegible].35 ef | [illegible].46 |
| Loamy Sand Topdressed | Rake | 15.63 g | 25.3[illegible] |
| | Broadcast | 15.2[illegible] g | 23.49 |
| | Pack | 13.75 g | 2[illegible].46 |
| | Mulch | 15.63 fg | 23.65 |

[1]. Means followed by same letter are not significantly different at P≤0.01

[2] Overall treatment means were not significant at P≤0.01

results. The packing may have caused the soil surface to crust. Soils high in free lime are prone to surface crusting and the packing may have aggravated the problem (Russell, 1973). A surface crust could restrict plant emergence and permeability of the soil to water. Regardless of whether a crust formed or not, packing the soil may have decreased porosity and inhibited infiltration of precipitation. Further, by reducing soil pore size, the transfer of heat to lower soil depths is enhanced by packing. This could result in the surface soils warming slowly in the spring and ultimately delaying plant development.

During the 1977 growing season, the mulched plots appeared to produce more plant cover than the other seeding methods. However, in the spring of the second growing season the mulched plots were inferior to all other seeding methods and remained so throughout the field experiments. There are several possible explanations for the negative effect of the mulch.

The application of mulch apparently enhanced retention of fertilizer as fertilization had its most pronounced effect on mulched plots (Table 17). However, Cundell (1977) found that the application of mulch produced a negative effect on plant growth one year after application because available nitrogen in the soil was being immobilized by microorganisms decomposing the mulch. The importance of soil fertility was demonstrated in greenhouse experiments, and nitrogen immobilization may have contributed to the poor results, especially on unfertilized plots.

The ability of the mulch to retain water can cause cooler soil temperatures in the spring as a result of better internal transfer of heat. The mulch also had lost much of its original green color by the second growing season and was nearly white. The higher albedo of the mulch would cause reflection of more radiant energy than on plots seeded by other methods. Consequently, it is probable that the mulch inhibited growth by causing the soil to warm slowly. Hopkins (1954) recorded cooler spring temperatures and a retardation of growth on mulched plots on a seeded grassland. The apparent delay of plant development as a result of cool spring soil temperatures did not persist as long on in mulched plots as it did on the peat topdressings. This is likely because the mulch was applied at approximately one half the rate of the peat. On soil topdressed with peat, mulching produced the poorest cover of any seeding method, probably because mulch compounded problems with immobilization of nitrogen and soil temperature on the organic soils.

It is possible that the depth of mulch was excessive. Plummer *et al.* (1955) found that optimal seeding depth was 1 to 2 cm for large seeds and 0.5 cm for small seeds. In this study, the average depth of mulch was 5 cm and ranged up to 8 cm in places. However, if excessive, the mulch likely would have inhibited the establishment of species with small seeds more than those with large seeds and any inhibition of plant establishment should have been most pronounced in the first growing season. Neither situation occurred in the field experiments since no relationship between seed size and establishment was identified and the mulched plots appeared to produce the greatest ground cover of the seeding method treatments in the first growing season. Consequently, the poor results achieved with mulching relative to other seeding methods do not appear to have been related to excessive depth of mulch.

Two of the main objectives of applying mulch were to reduce erosion and to increase moisture in the seedbed. As discussed above, erosion did not appear to be a significant factor in either growing season. Furthermore, precipitation was above normal both years and any increase in seedbed moisture may not have been of benefit. Enhanced moisture retention may have been of some benefit on the soils topdressed with loamy sand as the mulched plots were superior to the other seeding methods with the exception of raking. Had precipitation been lower in both growing seasons, mulch may have been more successful on the coarser soils.

## 5.9 Topdressing, Fertilizing and Seeding Method Treatments

In combination, topdressing, fertilizing and seeding methods did not significantly affect percent ground cover. Furthermore, the three factor interactions were too complicate .o allow interpretation from the data collected.

Nevertheless, some discussion of the combined treatments is warranted.

Packing the seed into fertilized soils that were not topdressed produced the greatest average ground cover, 39.37 percent (Table 19). In comparison, the combination of the most successful single treatments, not topdressing, fertilizing and raking, produced an average cover of 37.08 percent. On fertilized plots that were not topdressed, raking the seed into the seedbed was the poorest overall seeding method and even raking fertilized soils, topdressed with peat produced better ground cover. The results exemplify the potential problems with 'selecting' a combination of treatments on the basis of results from single factor analyses.

The simplest treatment, broadcasting seed onto unfertilized, non-topdressed soils, produced an average of 35.74 percent ground cover. This was 5.41 percent greater than the overall cover on the treated plots and only 3.63 percent less than the best overall treatment. Apparently, the combined effect of the experimental constants (rototilling the seedbed and seeding the area) was more beneficial than the treatments which were tested. This was probably largely due to the favourable weather in both growing seasons. However, the results do indicate that the gravelly seedbed surface prior to rototilling and the lack of a sufficient seed source at the site were major limiting factors to natural secondary succession.

Table 19: Means of Combined Topdressing, Fertilizer and Seeding Method Treatments[1]

| Treatments | | | Percent Ground Cover (1978 Average) |
|---|---|---|---|
| Not Topdressed | - Unfertilized | - Rake | 33.75 |
| | | - Broadcast | 35.74 |
| | | - Pack | 31.16 |
| | | - Mulch | 26.35 |
| | - Fertilized | - Rake | 37.08 |
| | | - Broadcast | [illegible] |
| | | - Pack | [illegible] |
| | | - Mulch | [illegible] |
| Peat Topdressed | - Unfertilized | - Rake | 31.77 |
| | | - Broadcast | 32.82 |
| | | - Pack | 27.81 |
| | | - Mulch | 30.94 |
| | - Fertilized | - Rake | 38.75 |
| | | - Broadcast | 32.40 |
| | | - Pack | 34.69 |
| | | - Mulch | 31.98 |
| Loamy Sand Topdressed | - Unfertilized | - Rake | 17.60 |
| | | - Broadcast | 15.73 |
| | | - Pack | 19.59 |
| | | - Mulch | 19.79 |
| | - Fertilized | - Rake | 33.02 |
| | | - Broadcast | 31.24 |
| | | - Pack | 23.33 |
| | | - Mulch | 27.50 |

1 Treatments not significant at $P \leq 0.01$

# 6. SUMMARY AND CONCLUSIONS

The objectives of this research were to determine the potentials of various treatments to establish vegetation under harsh conditions. Careful attention was given to the selection of a site where harsh environmental conditions were prevalent. The treatments selected for experimentation were those that showed potential to overcome site limitations. However, weather conditions in both growing seasons included in the research were more favourable to the establishment of vegetation than the long-term average. It is probable that favourable weather significantly positively affected the results of the field experiments.

In normal years, the study site is dry and windy with soil moisture below permanent wilting point for about one-third of the growing season. However, in both growing seasons precipitation was well above average and temperatures were below average. The soils of the study site were found to be nutrient-poor especially with respect to nitrogen and phosphorus. Alkaline soil conditions may also have induced deficiencies of several micro-nutrients such as iron, manganese, zinc, cobalt, copper and boron. The soils were gravel-rich especially at the surface. Erosion appeared to have been an important factor at the site in the past but no evidence of erosion was noted in either growing season. The study site was also overgrazed.

Germination tests showed that large grass seeds and legumes used in the experiments had good germinability. Most shrub seeds and small-sized grass seeds failed to germinate. Improper storage and handling procedures probably caused a reduction in viability of the shrub and small grass seeds. Germination rates appeared to be related to seed size, since small seeds germinated rapidly relative to larger seeds. Rapid germination when conditions are suitable may be an evolutionary strategy of small seeds to enable plant establishment before stored food reserves are exhausted. With the exception of the small seeds, germination occurred over a long period of time. This also may be an adaptation of native plants to ensure that all germinants do not get killed by one disastrous event.

In general, those species that were successful in the field experiments were those that displayed good germinability under the treatments used in the germination tests. Similarily, those species that failed to establish or produced little ground cover had poor germinability. This correlation indicates that the viability of the seed was generally more important than the tolerance of the species to the habitat characteristics of the site.

Topdressing the seedbed was not beneficial. While soil tests showed no significant differences, greenhouse experiments indicated that both peat and loamy sand topdressings were less fertile than the original soils. Lower fertility was likely the major cause of the negative results from topdressings. The peat topdressing was probably too shallow to have significantly improved soil moisture levels and above-average precipitation probably overcame any beneficial effects on moisture-holding capability that the peat may have produced. Further, a delay in plant development was noted on soils topdressed with peat. The delay was attributed to cooler spring soil temperatures which result from greater moisture levels. Applying loamy sand topdressing did little to improve the physical characteristics of the soil surface since simply rototilling the site had buried much of the surficial gravel that had inhibited natural revegetation. Plant species varied in their ability to establish on a given topdressing treatment.

Applying fertilizer, (16-20-0 + 14% S) at 785 kg/ha, significantly improved ground cover in the field and plant weight and height in greenhouse experiments. Fertilizing increased ground cover 6.81 percent overall. Increases in ground cover from fertilization did not appear to diminish in the second growing season, although soil tests indicated that the applied nutrients had become almost completely unavailable. It is possible that fertilization encouraged the development of a more productive plant-nutrient cycle, whereby increases in detrital input equaled increases in mineralization of organic matter. No plant species showed a negative response to fertilization.

Some of the fertilizer was absorbed by the growing plants. However, a significant amount of ammonium nitrogen was likely lost by volatization of ammonia. Covering the fertilizer by raking it into the seedbed or mulching appeared to inhibit volatization. Much of the applied phosphorus probably formed calcium compounds with low solubilities, a common fate of phosphorus in alkaline soil. Banding the phosphorus may have been a more appropriate method of application. Some of the applied sulfate sulfur appeared to be available after two growing seasons. The application of acid-forming fertilizer did not produce a decrease in soil pH two growing seasons after application. This is likely a result of loss of acid-forming material from volatization and leaching of fertilizer in conjunction with deposition of calcareous loess.

The beneficial effects of fertilization were more pronounced in the soils topdressed with loamy sand, which were the least fertile soils. Fertilization was also more effective on soils topdressed with peat than soils not topdressed in greenhouse experiments. The results indicate that fertility was more important than moisture holding capacity when moist conditions prevailed.

The method of seeding did not affect overall percent ground cover. Differences in plant establishment in the first growing season and in the early part of the second were noted. However, it appeared that encroachment of established vegetation overcame the differences in a short period of time. Raking the seed into the seedbed produced the most ground cover on the fertilized plots and the soils with lower fertility (those topdressed with loamy sand and peat). This is likely due to an inhibition of volatization of ammonium fertilizer. Mulching was the poorest seeding method probably as a result of a retarding effect on warming of soil in the spring and an immobilization of available nitrogen from microorganisms decomposing the organic matter. The method of seeding did not affect establishment among species.

Ground cover on the treated plots averaged 30.33 percent in the second growing season in comparison to 9.5 percent achieved from 25 years of natural succession. Packing the seed into fertilized soils that were not topdressed produced the greatest ground cover, 39.37 percent. The combination of the most successful single treatments, no topdressing, fertilizing and raking, produced only 37.80 percent cover, which points out the hazards of selecting a combination of treatments on the basis of results from single factor analyses. Simply broadcasting seed onto an unamended, rototilled surface produced ground cover of 35.74 percent. This indicates that the gravelly seedbed surface and the lack of a sufficient seed source were major limiting factors.

The success of revegetation should be determined in the long term. Variations in weather will determine the significance of possible cool spring soil temperatures and improvements in moisture availability from topdressing with peat or mulching. An enhancement of soil nitrogen availability by legumes would not be realized in two growing seasons. Ludeke (1977) found that plants that established and grew rapidly often did not live beyond 2 or 3 years as they were not truly drought tolerant like slow-growing plants. The same may be true of plants that are not tolerant of low fertility. Further, effects of grazing activities are difficult to assess from two years of observations. Moore *et al.* (1975) suggested that stability, as defined by a resistance to change, can be reached in 8 to 10 years if weather is variable. Consequently, the results of these experiments are preliminary in nature.

Nevertheless, the initial results presented in this thesis indicate the possibility of rapid establishment of a productive native plant community in a harsh mountain environment. If weather conditions are suitable, proper seedbed tillage and broadcast seeding alone can be sufficient to successfully establish ground cover.

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APPENDIX A

# APPENDIX A: VASCULAR SPECIES IDENTIFIED IN BOTANICAL SURVEYS OF THE WINDY POINT AREA

*Pinaceae*

*Juniperus communis* L. [1,2,3]

*Juniperus horizontalis* Moench.[1]

*Picea glauca* (Moench) Voss [2,3]

*Pseudotsuga menziesii* (Mirb.) Franco[2]

*Gramineae*

*Agropyron dasystachyum* (Hook.) Scribn.[1]

*Agropyron riparium* Scribn. & Smith[1]

*Agropyron trachycaulum* (Link) Malte[1]

*Bromus pumpellianus* Scribn.[1 2]

*Calamagrostis montanensis* Scribn.[1]

*Calamagrostis purpurascens* R.Br. [1 2]

*Danthonia intermedia* Vasey[3]

*Elymus innovatus* Beal [1 2 3]

*Festuca saximontana* Rydb.[3]

*Koeleria cristata* (L.) Pers. [1 3]

*Poa interior* Rydb.[1]

*Poa pratensis* L.[3]

*Stipa richardsonii* Link[3]

*Cyperaceae*

*Carex concinna R.Br.*[3]

*Carex eleocharis Bailey*[1,3]

*Carex foenea Willd.*[1]

*Carex retrorsa Schwein*[2]

*Carex xerantica Bailey*[1]

*Salicaceae*

*Salix glauca L.*[3]

*Santalaceae*

*Comandra pallida A.DC.*[1]

*Chenopodiaceae*

*Salsola kali L. var. tenufolia Tausch*[1]

*Caryophyllaceae*

*Cerastium arvense L.*[3]

*Ranunculaceae*

*Anenome multifida Poir.*[1,2,3]

*Anenome patens L. var. wolfgangiana (Bess.) Koch*[1]

*Rosaceae*

*Fragaria virginiana Duchesne*[3]

*Potentilla fruticosa L.*[1,3]

*Rosa acicularis Lindl.*[2,3]

*Rosa woodsii Lindl.*[1]

*Leguminosae*

*Astragalus striatus Nutt*[1]

*Hedysarum alpinum L.*[1]

*Hedysarum mackenzii Richards.*[2,3]

*Lathyrus ochroleucus Hook*[2]

*Oxytropis sericia Nutt.*[1,3]

*Linaceae*

*Linum lewisii Pursh*[1,3]

*Elaeagnaceae*

*Elaeagnus commutata Bernh.*[3]

*Sheperdia canadensis (L.) Nutt.*[2,3]

*Onagraceae*

*Epilobium angustifolium L.*[2]

*Ericaceae*

*Arctostaphylos uva-ursi (L.) Spreng*[2,3]

*Boraginaceae*

*Lithospermum ruderale Lehm*[1]

*Scrophulariaceae*

*Castilleja minitata Dougl.*[1]

*Penstemon confertus Dougl.* [3]

*Rubiaceae*

*Galium boreale L.*[1,2]

*Caprifoliaceae*

*Symphoricarpos albus (L.) Blake*[1]

*Campanulaceae*

*Campanula rotundifolia L.*[1,2]

*Compositeae*

*Achillea millefolium L.*[1,2]

*Antennaria nitida* Greene [1 3]

*Artemisia frigida* Willd.[1 2 3]

*Aster conspicuus* Lindl.[1 2]

*Erigeron caespitosus* Nutt.[1 2 3]

*Gaillardia aristata* Pursh[1 3]

*Senecio canus* Hook.[3]

*Senecio cymbalariodes* Nutt.[1 3]

*Solidago decumbens* Greene[1 2 3]

[1]Identified by Stringer (1969).

[2]Identified by Hettinger (1975).

[3]Identified by Wells *et al.* (1978).

## APPENDIX B

# APPENDIX B: DETAILED DESCRIPTION OF PLANT MATERIALS

1. *Juniperus horizontalis* (Creeping Juniper)

*Juniperus horizontalis* is common on slopes throughout Alberta's Rocky Mountains (Moss 1977). Stringer (1969) identified the species in his botanical survey of the Windy Point area. The particular population used in the field experiments originated on the montane grasslands at Kootenay Plains near the Big Horn Dom, Alberta.

*J. horizontalis* most frequently occupies sandy and rocky soils (Moss 1977). Porsild (1974) stated that the species is almost always found on calareous soils. *J. horizontalis* is very drought tolerant and has low soil nutrient requirements (Epps 1973).

*J. horizontalis* has not been extensively used for reclamation purposes. A number of authorities have recommended it for further research (Peterson and Etter 1970, Epps 1973, Watson *et al.* 1980).

2. *Agropyron riparium* (Streambank wheatgrass)

*Agropyron riparium* is native to Alberta and Stringer (1969) identified the species near the site of the Windy Point field plots. The plant material utilized in the experiments described in this text is the certified grass variety Sodar. Sodar breeding stock originated from a dry, mountainous area of Oregon at a elevation of about 1000 m and annual precipitation of 30 cm (Elliott and Bolton 1970). The species occurs in both natural and revegetation settings at over 1600 m in Alberta's foothills (Walker et al. 1977, Lesko *et al.* 1975).

Variety Sodar was developed for erosion control purposes and is both drought resistant and alkaline tolerant (Hanson 1965). It produces an open sod and has a rhizomatous root system which produces a very high soil stabilization ability (Elliott and Bolton 1970).

Sodar has been successfully used in revegetation trials at Luscar, Alberta (Etter 1971, Lesko *et al.* 1975), which is a less than 80 km from the Windy Point study site. It has also been successful on the coarse-textured Athabasca tailing sands at Fort McMurray, Alberta (Lesko 1974, Syncrude Canada Ltd. 1975, Rowell 1979).

3. *Agropyron trachycaulum* (Slender Wheatgrass)

*Agropyron trachycaulum* is a species native to North America with a wide continental distribution. Stringer (1969) identified the species in his botanical investigation in the Windy Point area. Plant and seed collections of *A. trachycaulum* have been made at elevations up to 2600 m at Ram Mountain, Alberta (Walker *et al.* 1977). The particular population used in the field and greenhouse experiments originated near Beaverlodge, Alberta, and the seed stock was multipled on a seed farm in the Beaverlodge area.

*A. trachycaulum* is a bunchgrass with a fibrous root system (Hanson 1965). It is moderately to highly tolerant of alkaline soil conditions (Hanson 1965, Smoliak *et al.* 1975). Russell and Takyi (1979) found that *A. trachycaulum* was successful in revegetating coarse textured overburden with a pH 8.8 at Cadomin, Alberta. The species has also been rated as relatively drought tolerant (Smoliak *et al.* 1975).

*A. trachycaulum* has proven to be successful in naturally revegetating disturbed sites. Vaartnou and Wheeler (1974) wrote that in Alberta:

> "the species provided cover in all areas of the province, including coarse textured, high pH [and] high free lime soil... and is a very important species in providing the initial cover on disturbed areas."

The species has also proven successful in many revegetation experiments. Macyk (1974) found *A. trachycaulum* to be one of the better grasses for revegetating mine tailings at Grande Cache, Alberta. Revegetation experiments at Blairmore, Alberta, proved *A. trachycaulum* to be a suitable species for dry mountain areas (Regier 1974). Further, *A. trachycaulum* was successfully used in revegetation trials in Athabasca tailing sands (Syncrude Canada Ltd. 1975).

4. *Agropyron* sp. (Wheatgrass)

The third population of *Agropyron* was never taxonomically classified to the species level. It appears to be a hybrid or a population that has become morphologically differentiated, since its characteristics are not diagnostic of any *Agropyron* indigenous to Alberta (Vaartnou pers. comm.). The breeding stock originated near Beaverlodge, Alberta, and the seed stock was multipled at a seed farm in the same area.

While *Agropyron* sp. appeared to be a vigorous plant material at the collection site and at the seed farm, it had not been tested on revegetation trials prior to the Windy Point experiments.

5. *Agrostis stolonifera* (Red top)

*Agrostis stolonifera* is an introduced species brought to Canada from Poland to be used as a cultivated forage crop (Hanson 1965). The species is so well adapted to Alberta's environments that it has become widely established under natural conditions (Scoggan 1979). The species has a strong rhizomatous and stoloniferous habit and provides good erosion control (Hanson 1965). However, *A. stolonifera* is generally not tolerant to long periods of drought (Smoliak *et al.* 1975).

*A. stolonifera* has performed well in revegetation trials on the Athabasca Tar Sands (Syncrude Canada Ltd. 1975). The species has also been successfully used to revegetate mine tailings at Luscar, Alberta (Etter 1971) and has performed well in revegetation trials above 1600 m in elevation (Watson *et al.* 1980). *A. stolonifera* is also commonly used to revegetate mine spoils on dry montane grasslands in southeastern British Columbia (Ziemkiewicz and Northway 1978).

6. *Elymus innovatus* Beal (Hairy Wild Rye)

*Elymus innovatus* is native to the lower ranges of Alberta's Rocky Mountains (Watson *et al.* 1980). The species was identified in three floristic studies on grasslands in the Windy Point area (Stringer 1969, Hettinger 1975, Wells *et al.* 1978). The population used in the Windy Point experiments originated near Fort St. John, British Columbia. The seed stock was multiplied at a seed farm at Ellerslie, Alberta.

*E. innovatus* grows well on coarse and gravelly soils (Vaartnou and Wheeler 1974, Walker *et al.* 1977). It has a deep spreading rhizomatous root system and provides good erosion control (Vaartnou and Sons Ent. Ltd. 1977).

The species has been successfully used in several revegetation studies. *E. innovatus* was successful in establishing ground cover on pipeline rights-of-way in northeastern British Columbia (Vaartnou and Sons Ent. Ltd. 1977). It also performed well on Athabasca tailing sands (Syncrude Canada Ltd. 1975). Macyk (1977) found good growth rates of *E. innovatus* on mine tailings from Grande Cache, Alberta.

7. *Festuca saximontana*

*Festuca saximontana* is a common native Alberta grass, which usually occurs on open areas with dry soils (Moss 1977). Wells *et al.* (1978) identified the species in their botanical surveys in the field area. The particular population used in the field experiments was collected from the Kootenay Plains montane grasslands. The seed stock was multiplied on a seed farm near Peers, Alberta.

*F. saximontana* is a densley tufted, low growing bunch grass (Moss 1977). The species is generally considered to be a good soil stabilizer. No research has been conducted as to its tolerance to alkaline conditions. However, its presence on undisturbed sites at Windy Point indicate it is adapted to such conditions.

*F. saximontana* has not been extensively used in revegetation work. This can be attributed to the fact that it is botanically very similar to *F. ovina* L., which is commercially available. Syncrude Canada Ltd. (1975) has utilized *F. saximontana* in revegetation experiments and had good success on Athabasca tailing sand materials.

8. *Koeleria cristata* (June Grass)

*Koeleria cristata* is circumboreal in distribution and native to Alberta (Moss 1977). Wells *et al.* (1978) and Stringer (1969) identified this species in the Windy

Point area. *K. cristata* is common to the dry, open grassland slopes of Alberta's foothills and mountains (Budd and Best 1976). The population used in the field experiments originated in the Peace River region of Alberta, and the seed stock was multiplied at Beaverlodge, Alberta.

*K. cristata* is a low tufted bunch grass (Moss 1977). It commonly occupies excessively drained Regosolic soils has performed well on alkaline soils (Watson *et al.* 1980).

Vaartnou and Wheeler (1974) found *K. cristata* to be a suitable species for reclamation trials on coarse-textured soils. Good success was also achieved with *K. cristata* in revegetation trials at Luscar, Alberta (Etter 1971, Lesko *et al.* 1975).

9. *Poa alpina* (Alpine bluegrass)

*Poa alpina* is native to Alberta and common throughout the Rocky Mountains (Moss 1977). Two populations of *P. alpina* were selected for the revegetation studies at Windy Point. One population originated on a gravelly loam soil near Pine Pass, British Columbia, and the seed stock was multiplied near Peers, Alberta. This population was referred to as *Poa alpina* #1. The origin of the second population, *Poa alpina* #2, is unknown. Records regarding the collection of this plant material were lost.

*P. alpina* is a densly tufted, bunchgrass (Budd and Best 1976). It commonly occupies dry, gravelly mountain slopes and is also well adapted to calcareous conditions (Scoggan 1979, Polster 1975).

*P. alpina* has been recorded as an active colonizer on numerous disturbed mountainous areas (Brown *et al.* 1976, Polster 1975). It has been successfully seeded on road cuts at elevations up to 3000 m in the Rocky Mountains of Colorado (Harrington 1946). *P. alpina* also performed well in growth trials of alpine mine disturbances in Montana (Brown and Johnston 1978).

10. *Poa pratensis* (Kentucky bluegrass)

*Poa pratensis* is common throughout the northern hemisphere and is considered native to central and northern Alberta (Moss 1977). The species was identified by Wells *et al.* (1978) in the Windy Point area. The particular population used in the field and greenhouse experiments was collected from Palmer, Alaska, and seed stock was multipled on a seed farm near Beaverlodge, Alberta.

*P. pratensis* has a rhizomatous rooting habit and is sod-forming (Moss 1977). It is considered to be an excellent grass for controlling erosion and promoting soil stability (Plummer *et al.* 1955). *P. pratensis* grows well on well-drained soils of limestone origin (Hanson 1965). However, it is also adapted to a wide range of soil groups and soil textures (Watson *et al.* 1980).

Largely because of its commercial availability, *P. pratensis* is one of the most widely used species in revegetation operations. Etter (1971) and Lesko *et al.* (1975) had good results when *P. pratensis* was seeded on mine spoils at Luscar, Alberta. Macyk (1974) found the species to be successful in revegetation trials on a strip-mine near Grande Cache, Alberta. Selner (1975) reported that *P. pratensis* was the most successful of any of the grasses seeded on coal mine spoils at Sterco and Lovett, Alberta. *P. pratensis* also produced good ground cover when seeded on topdressed coal overburden at Cadomin, Alberta (Russell and Takyi 1979).

11. *Rosa acicularis* (Prickly rose)

*Rosa acicularis* has an extensive natural range and is native to Alberta (Moss 1977). The species was identified by Stringer (1969), Hettinger (1975) and Wells *et al.* (1978) in their botanical surveys of the Windy Point area. The particular population used in the field trials was collected from the Cypress Hills, Alberta.

The species has great genetic variability and consequently occupies many different environments (Moss 1977). Vaartnou and Wheeler (1974) determined that populations of *R. acicularis* are suitable for revegetation of coarse-textured soils with high pH and high levels of free lime. Fedkenheuer and Langevin (1978) had good survival of *R. acicularis* on amended tailing sands north of Fort McMurray, Alberta. However, more research has been recommended to select specific populations for use on disturbed sites (Watson *et al.* 1980).

12. *Astragalus* sp. (Milk Vetch)

*Astragalus* is a wide spread genus of nitrogen fixing legumes and many species are native to Alberta (Moss 1977). The particular population used in the Windy Point experiments could not be taxonomically identified to the species level. It appeared to be a hybrid or has become morphologically differentiated to a point at which its characteristics are no longer diagnostic of any species of native *Astragulus* (Vaartnou pers. comm.). The population was collected from the Kootenay Plains, Alberta. Stringer (1969) identified an *Astragulus* (*A. striatus* Nutt.) in his botanical survey of the Windy Point area.

*Astragulus* is adapted to several soil types with coarse textures (Smoliak *et al.* 1975). *Astragulus cicer* L. has been observed as being especially well adapted to limestone derived soils and shallow, coarse textured subalpine soils (Kenny and Cuany 1978).

Because of its ability to fix atmospheric nitrogen, *Astragulus* can be considered desirable for revegetation purposes. It is currently being tested in grass-legume mixes on disturbed oil sands near Fort McMurray, Alberta (Fedkenheuer and Langevin 1978). *Astragalus cicer* generally failed to survive when seeded on a high elevational site (1950 m) in the Alberta's Rocky Mountains (Selner 1973) and on coal mined land at Trent Mountain, Alberta (Selner *et al.* 1977). However, it has been successful on high elevational trials in Colorado (Kenny and Cuany 1978), and Watson *et al.* (1980) suggested that it warranted further research.

13. *Hedysarum alpinum* L.

*Hedysarum alpinum* is native to prairies and open woods of Alberta (Moss 1977). The species was identified by Stringer (1969) and Wells *et al.* (1978) in the Windy Point area. The population utilized in the field trials originated near Peers, Alberta.

*H. alpinum* is common on calcareous sands, gravels and rocky slopes throughout Alberta (Scoggan 1979). It grows on poorly developed colluvial materials as well (Watson *et al.* 1980).

*H. alpinum*'s ability to fix atmospheric nitrogen allows successful establishment on relatively infertile soil materials (Klebesadel 1971). The species performed poorly when seeded on coal mine spoils at Grande Cache, Alberta (Macyk 1974). However, Syncrude Canada Ltd. (1975) reported good results with seeded *H. alpinum* on tailing sands near Fort McMurray, Alberta. Bamberg and Major (1968) concluded that the species showed good potential for revegetation of high elevation calcareous coal mine spoils in Montana as *H. alpinum* was found to be an early colonizer on such sites.

14. *Hedysarum mackenzii* Richards

*Hedysarum mackenzii* is native to Alberta and occurs on open areas in the Rocky Mountains (Moss 1977). Hettinger (1975) identified the species in the area of Windy Point. The population used in the field trials was collected from Haines Junction, Yukon.

The species commonly occupies calcareous gravels and rocky slopes (Scoggan 1979). Heusser (1956) identified *H. mackenzii* as an early colonzier of raw moraines in the Rocky Mountains. Tisdale *et al.* (1966) found the species to be a pioneer plant on moraines near Mount Robson, British Columbia.

No documented use of *H. mackenzii* for revegetation purposes could be located at the time of writing. However, its natural habit of colonizing calareous, gravelly mountain slopes and its ability to fix atmospheric nitrogen indicated that it had good potential as a revegetation material. Watson *et al.* (1980) suggested that the species warranted further research in this regard.

15. *Elaeagnus commutata* Bernh. (Silverberry)

*Elaeagnus commutata* is a native Alberta shrub (Moss 1977). The species was identified in the Windy Point area and is common on disturbed areas throughout Jasper's Athabasca River valley (Wells *et al.* 1978). The population used in the field experiments was collected from High Level, Alberta.

*E. commutata* is common on valley slopes including those with rocky, south-facing exposures (Moss 1977). It prefers well drained soils and does well on soils with low nutrient status (Peterson and Peterson 1977). *E. commutata* has the ability to fix nitrogen and thus can enhance soil productivity (Watson *et al.* 1980).

The species is well-adapted to sites with high erosion potential and has been effectively used to control erosion (Dick 1974). Lesko *et al.* (1975) reported good establishment of *E. commutata* on coal mine tailings at Luscar, Alberta. Fedkenheuer (1979) had 67 percent survival for fall planted seedings on tailing sands at Fort McMurray, Alberta.

# APPENDIX C: SOIL TEST RESULTS

## SOIL TEST RESULTS FOR SOILS AND TOPDRESSING PRIOR TO TREATMENT[1]

| MATERIAL | SAMPLE DEPTH (cm) | AVAILABLE PLANT NUTRIENTS[2] (ppm) (N) | (P) | (K) | SULFUR[3] | SOIL REACTION (pH) | SOIL CONDUC-TIVITY (mmhos) | SULFATES | SODIUM | FREE LIME[3] | ORGANIC MATTER[3] | TEXTURE[4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Study Site Soil | 0-15 | 1 | 0 | 113 | M- | 8.3 | 0.4 | NIL | L- | H+ | L | SL |
| | 16-30 | 0.5 | 0 | 66 | M- | 8.8 | 0.4 | NIL | L- | H+ | L | SL |
| Adjacent Undisturbed Soil | 0-15 | 2 | 0 | 137 | M | 8.2 | | NIL | L- | H+ | L | SL |
| | 16-30 | 51 | 0 | 107 | M | 8.7 | | NIL | L+ | H+ | L+ | L |
| Feathermoss & Sphagnum Peat Topdressing | N/A | 1.5 | 0 | 42 | M+ | 5.2 | 0.4 | NIL | L- | L | H+ | O |
| Loamy Sand Topdressing | N/A | 0.5 | 0 | 59 | L | 8.0 | 0.3 | NIL | L- | M+ | L | LS |

[1] Samples taken June 11, 1977

[2] N = Nitrogen
P = Phosphorus
K = Potassium

[3] Ranges are those of Alberta Agriculture Soil and Feed Testing Laboratory
Sulfur: L=1.1-2ppm, M=5.1-8ppm, M+=8.1-12ppm
Sodium: L=0-35ppm, L+=70.5-105ppm
Free lime: L=<1%, M+=6-8%, H+=>15%
Organic Matter: L=<1%, L+=1.1-2%, H+=>10%

[4] SL=Sandy loam, L=Loam, O=Organic, LS=Loamy Sand

## SOIL TEST RESULTS FOR TOPDRESSING AND FERTILIZER TREATMENT PLOTS[1]

| MATERIAL | SAMPLE DEPTH (cm) | AVAILABLE PLANT NUTRIENTS[2] (ppm) (N) | (P) | (K) | SULFUR[3] | SOIL REACTION (pH) | SOIL CONDUC-TIVITY (mmhos) | SULFATES | SODIUM | FREE LIME | ORGANIC MATTER[3] | TEXTURE[4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No Topdressing No Fertilizer | 0-15 | 1.5 | 0.5 | 109 | L+ | 8.2 | 0.4 | NIL | L- | H+ | L+ | SL |
| | 16-30 | 0.5 | 0 | 62 | L+ | 8.1 | 0.4 | NIL | L- | H+ | L+ | SL |
| No Topdressing Fertilized | 0-15 | 1 | 0.5 | 141 | L+ | 8.2 | 0.4 | NIL | L- | H+ | L+ | SL |
| | 16-30 | 4.5 | 0.5 | 67 | M- | 8.4 | 0.4 | NIL | L- | H+ | L+ | SL |
| Peat Topdressing No Fertilizer | 0-15 | 1.5 | 0 | 108 | M | 8.0 | 0.4 | NIL | L- | H- | H | O |
| | 16-30 | 1 | 0 | 85 | M | 8.1 | 0.4 | NIL | L- | H+ | L+ | SL |
| Peat Topdressing Fertilized | 0-15 | 1.5 | 1.5 | 24 | M+ | 7.8 | 0.4 | NIL | L- | M+ | H | O |
| | 16-30 | 0.5 | 0.5 | 52 | M+ | 8.2 | 0.3 | NIL | L- | H+ | L+ | SL |
| Loamy Sand Topdressing No Fertilizer | 0-15 | 0.5 | 0.5 | 57 | L | 8.5 | 0.3 | NIL | L- | H+ | L | LS |
| | 16-30 | 0.5 | 0 | 72 | L | 8.4 | 0.2 | NIL | L- | H+ | L | SL |
| Loamy Sand Topdressing Fertilized | 0-15 | 0.5 | 0 | 64 | L+ | 8.3 | 0.3 | NIL | L- | H+ | L | LS |
| | 16-30 | 0.5 | 0 | 65 | M- | 8.4 | 0.3 | NIL | L- | H+ | L | SL |

[1] Samples taken September 4, 1978

[2] N = Nitrogen
P = Phosphorus
K = Potassium

[3] Ranges are those of Alberta Agriculture Soil and Feed Testing Laboratory

Sulfur: L=1.1-2ppm, L+=2.1-3ppm, M-=3.1-5ppm, M-5.1-8ppm, M+=8.1-12ppm

Sodium: L-=0-35ppm

Free Lime: M+=6-8%, H-=8-10%, H+=>15%

Organic Matter: L=<1%, L+=1.1-2%, H=8-10%

[4] SL=Sandy Loam, L=Loam, O=Organic, LS=Loamy Sand

# APPENDIX D: ANALYSIS OF VARIANCE

ANALYSIS OF VARIANCE FOR SEED MIXTURES FOR FIELD EXPERIMENTS

| SOURCE OF VARIATION | DEGREES OF FREEDOM | SUM OF SQUARES | MEAN SQUARE | F VALUE |
|---|---|---|---|---|
| REPLICATION | 3 | 481.68 | 160.56 | 2.53 |
| SEASON (S) | 3 | 31099.53 | 10366.51 | 163.07* |
| ERROR #1 | 9 | 572.13 | 63.57 | |
| | | | | |
| TOPDRESSING (T) | 2 | 17330.60 | 8665.30 | 153.65* |
| T × S | 6 | 17033.29 | 2838.88 | 50.34* |
| ERROR #2 | 24 | 1353.55 | 56.40 | |
| | | | | |
| FERTILIZER (F) | 1 | 13624.24 | 13624.24 | 295.95* |
| F × S | 3 | 549.72 | 183.24 | 3.98 |
| F × T | 2 | 4062.27 | 2031.14 | 44.12* |
| F × S × T | 6 | 831.48 | 138.58 | 3.01 |
| ERROR #3 | 36 | 1657.29 | 46.04 | |
| | | | | |
| SEEDING METHOD (M) | 3 | 585.64 | 195.21 | 2.96 |
| M × S | 9 | 1646.64 | 182.96 | 2.77* |
| M × T | 6 | 736.00 | 122.67 | 1.86 |
| M × F | 3 | 193.89 | 64.63 | 0.98 |
| M × S × T | 18 | 2034.83 | 113.04 | 1.71 |
| M × S × F | 9 | 820.34 | 91.14 | 1.38 |
| M × T × F | 6 | 997.17 | 166.19 | 2.52 |
| M × S × T × F | 18 | 6356.30 | 353.13 | 5.35* |
| ERROR #4 | 216 | 14245.72 | 65.95 | |

| SOURCE OF VARIATION | DEGREES OF FREEDOM | SUM OF SQUARES | MEAN SQUARE | F VALUE |
|---|---|---|---|---|
| Seed Mixture (SE) | 2 | 321.64 | 160.82 | 3.21 |
| SE × S | 6 | 735.19 | 125.53 | 2.51 |
| SE × T | 4 | 222.31 | 55.58 | 1.11 |
| SE × F | 2 | 436.52 | 218.26 | 4.36 |
| SE × M | 6 | 324.45 | 54.08 | 1.08 |
| SE × S × T | 12 | 334.62 | 27.89 | 0.56 |
| SE × S × F | 6 | 1036.91 | 172.82 | 3.45* |
| SE × S × M | 18 | 554.44 | 30.80 | 0.62 |
| SE × T × F | 4 | 110.15 | 27.54 | 0.55 |
| SE × T ×M | 12 | 414.58 | 34.55 | 0.69 |
| SE × F × M | 6 | 479.66 | 79.94 | 1.60 |
| SE × S × T × F | 12 | 825.26 | 68.77 | 1.37 |
| SE × S × T × M | 36 | 2022.92 | 56.19 | 1.12 |
| SE × S × F × M | 18 | 1056.63 | 58.70 | 1.17 |
| SE × T × F × M | 12 | 739.03 | 61.59 | 1.23 |
| SE × S × T × F × M | 36 | 1686.67 | 46.85 | 0.93 |
| ERROR #5 | 576 | 28837.48 | 50.07 | |
| TOTAL | 1151 | 156381.16 | | |

* Significant at $P \leq 0.01$

## ANALYSIS OF VARIANCE FOR INDIVIDUAL SPECIES FOR FIELD EXPERIMENTS

| | Degrees of Freedom | Sum of Squares | Mean Square | F Value |
|---|---|---|---|---|
| REPLICATION | 3 | 40.82 | 13.61 | 0.48 |
| TOPDRESSING (T) | 2 | 889.25 | 444.63 | 15.59* |
| ERROR #1 | 6 | 171.07 | 28.51 | |
| | | | | |
| FERTILIZER (F) | 1 | 1589.07 | 1589.07 | 191.06* |
| F x T | 2 | 275.00 | 137.50 | 16.53* |
| ERROR #2 | 12 | 99.80 | 8.32 | |
| | | | | |
| SEEDING METHOD (M) | 3 | 28.57 | 9.52 | 0.47 |
| M x T | 6 | 125.65 | 20.94 | 1.03 |
| M x F | 3 | 54.21 | 18.07 | 0.90 |
| M x T x F | 6 | 239.43 | 39.90 | 1.99 |
| ERROR #3 | 5 | 1088.15 | 20.15 | |
| | | | | |
| SPECIES (S) | 11 | 18684.00 | 1698.55 | 138.73* |
| S x T | 22 | 11136.20 | 506.19 | 41.35* |
| S x F | 11 | 992.17 | 90.20 | 7.36* |
| S x M | 33 | 693.81 | 21.02 | 1.72 |
| S x T x F | 22 | 1570.28 | 71.38 | 5.83* |
| S x T x M | 66 | 1531.30 | 23.20 | 1.90* |
| S x F x M | 33 | 656.09 | 19.88 | 1.6 |
| S x F x F x M | 66 | 1253.86 | 18.99 | 1.55* |
| ERROR #4 | 792 | 9765.36 | 12.33 | |
| | | | | |
| TOTAL | 1151 | 50875.68 | | |

* Significant at P≤0.01

ANALYSIS OF VARIANCE OF WEIGHT MEASUREMENTS OF GREENHOUSE GROWN PLANTS

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F Value |
|---|---|---|---|---|
| TOPDRESSING (T) | 2 | 5128.54 | 2564.27 | 8.71* |
| FERTILIZER (F) | 1 | 56757.05 | 56757.05 | 192.68* |
| T × F | 2 | 850.53 | 425.67 | 1.44 |
| SPECIES (S) | 4 | 90241.95 | 22560.49 | 76.67* |
| S × T | 8 | 5453.02 | 681.63 | 2.31 |
| S × F | 4 | 43141.56 | 10785.39 | 36.61* |
| S × T × F | 8 | 7017.06 | 877.13 | 2.98 |
| ERROR | 120 | 35347.42 | 294.56 | |
| TOTAL | 149 | 243937.13 | | |

* Significant at P≤0.01

ANALYSIS OF VARIANCE OF HEIGHT MEASUREMENTS OF GREENHOUSE GROWN PLANTS

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F Value |
|---|---|---|---|---|
| TOPDRESSING (T) | 2 | 4995.31 | 2497.65 | 56.27* |
| FERTILIZER (F) | 1 | 27773.46 | 27773.46 | 625.66* |
| T x F | 2 | 3186.77 | 1593.38 | 35.89* |
| SPECIES (S) | 4 | 86270.97 | 21567.74 | 485.77* |
| S x T | 8 | 2127.43 | 265.93 | 5.98* |
| S x F | 4 | 9320.45 | 2330.11 | 52.48* |
| S x T x F | 8 | 2719.44 | 339.93 | 7.66* |
| ERROR | 720 | 31967.28 | 44.39 | |
| TOTAL | 749 | 168361.11 | | |

* Significant at P≤0.01