Plant establishment on tailings produced from talc production
by James Dillon Toole

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


Abstract:
Mining and the subsequent processing of talc ore results in the production of tailings material that is slurried into impoundments. This material is devoid of vegetation because of its inherent structural limitations and nutrient deficiencies. Potential environmental hazards result from sediments in runoff, erosion and fugitive dust particles. Talc tailings require amendments to enhance soil fertility and to provide a suitable medium for plant establishment and growth.

Talc tailings are neither saline nor sodic and they do not contain acid producing materials or toxic levels of metals. The objectives of this study were to identify talc tailings physicochemical properties that limit plant establishment and growth, evaluate plant productivity on talc tailings amended with manure and coversoil, and recommend a revegetation plan for talc tailings.

This project evaluated plant response on talc tailings material amended with three thicknesses (15.2 cm, 30.4 cm and 45.6 cm) of coversoil applications and with cow manure. Cow manure was added to attain a six percent organic matter content (dry weight) in the 0 - 25.4 cm depth increment of the tailings. The experiment was a randomized complete block design consisting of three blocks containing five plots each. The five plots consisted of the four treatments and a control. All plots were broadcast seeded with a seed mixture containing Agropyron spicatum, Agropyron smithii, Agropyron trachycaulum, Agropyron riparium, Elymus cinereus, Onobrychis viciaefolia, and Linum perenne.

Two way analysis of variance (ANOVA) statistical methods were used on all data sets and least significant difference (LSD) was used to calculate pairwise comparisons of the means when significant p-values were present. P-values less than 0.05 were considered significant.

After two growing seasons the manure treated plots had greater perennial grass cover than all other treatments. The coversoil plots generally exhibited greater cover than manure plots and controls' for both legumes and nonseeded species. Two coversoil applications (30.4 and 45.6 cm) had higher production than the control and the manure treatment for Onobrychis viciaefolia and all three coversoil thicknesses had greater production for Linum perenne. The 40.5 cm coversoil treatment had higher nonseeded forb production than all other treatments. The manure treatment exhibited greater production than the other treatments in the categories of Agropyron spicatum, Agropyron smithii, Agropyron trachycaulum, total seeded grasses and total vegetation.

When reclaiming tailings produced from talc processing, I recommend incorporating cow manure into the material. Plant cover and production will establish and develop more effectively.

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James Dillon Toole

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January 6, 1997 Douglas J. Dollhopf
Date Chairperson, Graduate Committee

Approved for the Major Department

1/6/97 M. W. Ross
Date Head, Major Department

Approved for the College of Graduate Studies

1/28/97 P. L. Brown
Date Graduate Dean

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# ABSTRACT

Mining and the subsequent processing of talc ore results in the production of tailings material that is slurried into impoundments. This material is devoid of vegetation because of its inherent structural limitations and nutrient deficiencies. Potential environmental hazards result from sediments in runoff, erosion and fugitive dust particles. Talc tailings require amendments to enhance soil fertility and to provide a suitable medium for plant establishment and growth.

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This project evaluated plant response on talc tailings material amended with three thicknesses (15.2 cm, 30.4 cm and 45.6 cm) of coversoil applications and with cow manure. Cow manure was added to attain a six percent organic matter content (dry weight) in the 0 - 25.4 cm depth increment of the tailings. The experiment was a randomized complete block design consisting of three blocks containing five plots each. The five plots consisted of the four treatments and a control. All plots were broadcast seeded with a seed mixture containing *Agropyron spicatum*, *Agropyron smithii*, *Agropyron trachycaulum*, *Agropyron riparium*, *Elymus cinereus*, *Onobrychis viciaefolia*, and *Linum perenne*.

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After two growing seasons the manure treated plots had greater perennial grass cover than all other treatments. The coversoil plots generally exhibited greater cover than manure plots and controls for both legumes and nonseeded species. Two coversoil applications (30.4 and 45.6 cm) had higher production than the control and the manure treatment for *Onobrychis viciaefolia* and all three coversoil thicknesses had greater production for *Linum perenne*. The 40.5 cm coversoil treatment had higher nonseeded forb production than all other treatments. The manure treatment exhibited greater production than the other treatments in the categories of *Agropyron spicatum*, *Agropyron smithii*, *Agropyron trachycaulum*, total seeded grasses and total vegetation.

When reclaiming tailings produced from talc processing, I recommend incorporating cow manure into the material. Plant cover and production will establish and develop more effectively.

# INTRODUCTION

The mining and subsequent processing of talc ore results in the production of tailings material that is slurried into impoundments for immediate storage. Stabilization of solid wastes produced by the mineral industry is a concern as these wastes account for 80% of the nation's non-agricultural, land-disposed solid wastes (Veith and Kaas 1988). Because of the land disturbance associated with talc mining and processing, knowledge of effective reclamation of the associated waste by-products is needed.

Talc tailings lack the necessary physical and chemical properties for the establishment of vegetation. Barren tailings pose a potential environmental concern because particles are susceptible to movement by water and wind. The public often considers impoundments unsightly. Thus, successful revegetation of these sites is desirable. Stabilization of mine waste through vegetation establishment should accomplish one or more of the following goals: 1) dust control, 2) erosion control to prevent impoundment wall rupture, 3) erosion control to prevent runoff of surface particles and subsequent sediment deposition in water courses, 4) a reduction in water percolating through mine wastes, 5) aesthetic improvement of the waste areas, and 6) acceleration of natural succession on waste areas (Watkin and Watkin 1982).

Primary challenges of mine tailings reclamation are often associated with inadequate levels of organic matter and plant nutrients for sustained plant growth, low water holding capacity, and limited soil microbial populations that are essential for nutrient cycling (Redente and Baker 1996). Organic amendments and coversoil additions have been used to restore these characteristics and to facilitate plant establishment on many types of mining related disturbances. This ecological approach is often effective in reestablishing a self-sustaining plant community and therefore is a desirable method for reclamation because of the associated low cost and low maintenance over the long term.

Large deposits of pure talc have been mined in southwestern Montana for more than 65 years. The research site located at the Barretts Minerals, Incorporated processing facility near Dillon, Montana, was selected to accomplish the following objectives:

- identify talc tailings physicochemical properties that limit plant establishment and growth,
- evaluate plant productivity on talc tailings amended with manure and coversoil, and
- recommend a revegetation plan for talc tailings.

# LITERATURE REVIEW

The mineral industry in many countries accounts for a major percentage of gross national products in many countries (Ritcey 1989). Talc is an important mineral resource that is mined throughout much of the world. China, Japan and the United States accounted for most of the world's talc production in 1992 with Finland, France and Brazil as the next primary producers (Virta 1992). North America is the largest consumer of talc with Europe and Japan roughly equal as next largest consumers (Burger 1991). The largest U.S. minerals producers of talc are Dal Tile, Gouverneur Talc Co., Luzenac NA and Pfizer Inc. Talc de Luzenac (France) is the largest producer in the world (Johnson 1994). The U.S. Bureau of Mines reports that the U.S. production of talc in 1992 was about 997,000 (910,000,000 kg) valued in excess of $31 million (Johnson 1994).

The high quality talcs in the United States are concentrated in Montana, Vermont and New York (O'Driscoll 1992). In 1992, Montana led all states in total tonnage and value of talc produced (Johnson 1994). The deposits in Montana are noted for their purity and large size. Ore zones which are virtually 100% talc can be traced for several hundred meters in Montana (Brady and Cheney 1991).

## Mineral Talc

Talc is a hydrous magnesium silicate; its formula is commonly given as $Mg_3Si_4O_{10}(OH)_2$ (Chidester and Worthington 1962). The mineral composition of talc mined in Montana is essentially talc with minor chlorite, dolomite, calcite and quartz (Johnson 1994). It is a layer silicate (Berg 1979). Other names for talc include steatite, soapstone (a massive form of the mineral) and grinding talc. Talc is characterized by its softness (it ranks one on the mohs scale), light-gray and greenish to white color and slippery feel.

## Talc Formation

Formation of economically viable talc deposits is generally restricted to two geologic environments: 1) metamorphosed siliceous dolomitic carbonate rocks; and 2) altered ultramafic bodies (Anderson 1987). Talc deposits are products of both contact and regional metamorphic processes (Chidester and Worthington 1962). Metamorphosed dolomitic carbonate is the primary process behind talc formation in the Ruby Range of southwestern Montana. The dominant process governing talc formation is the replacement of dolomite by talc (Larson 1991). This process can be described by the following reaction: 3 dolomite + 4 quartz + $H_2O$ = talc + 3 calcite + 3 $CO_2$ (Larson 1991). James (1990) suggests that hydrothermal fluids are the agent of this talc forming process. Sea water may have been the source of these fluids in the Ruby Range (Anderson et al. 1990).

The estimated temperature of talc formation is between 400 and 500$^0$C and there is some evidence that talc is more abundant in areas where marble has been tightly folded or where there are numerous faults (Berg 1979). Talc deposits are worldwide in distribution and range from Precambrian to Tertiary in age (Merrill 1963). The largest deposits in Montana occur in dolomitic marbles in the Cherry Creek series of early pre-Cambrian age in a region 40 miles across extending from Madison River Valley near Ennis to Blacktail Deer Creek Valley near Dillon (Perry 1948). Magnesite, quartz, chlorite, magnetite, serpentine, anthophyllite, tremolite, dolomite, and actinolite may be present as accessory minerals (Virta 1992).

## Commercial Uses of Talc

Talc has a wide range of commercial applications. By the industrial definition, the name "talc" is applied to rocks ranging in composition from those composed mainly of talc through those containing tremolite, serpentine, magnesite and other essential minerals (Merrill 1963). Commercial talcs range from products that have near-theoretical mineral composition to products that have physical and/or pyrophysical properties in common with pure talc but contain little of the actual mineral (Johnson 1994).

Critical properties of talc for industrial purposes include particle size and shape, the chemical composition of the mineral talc, and the identity and proportion of contaminant minerals (Merrill 1963). Other important characteristics for industry include its purity, fragrance retention, luster, moisture content, oil and grease adsorption, chemical inertness, low electrical conductivity and high thermal conductivity (Virta 1992).

The major domestic use for talc in 1992 was in ceramics, which accounted for 35% of the domestic consumption, followed by paper (20%), paint (18%), roofing (9%), plastics (5%) and cosmetics (5%) (Virta 1992). Pulp and paper mills are also large consumers of talc because of the importance of the mineral in pitch control.

## Talc Extraction and Processing

Most of the domestic talc production was from open pit mining operations: however, underground mining is used when a large waste-rock-to-ore ratio makes open pit mining uneconomical (Virta 1992). Drill holes are sampled to analyze the purity of the ore. These analyses enable the mine operator to plan the sequence of mining to provide talc of various grades for different markets (Berg 1979). These stockpiles can also be blended as needed.

The processing of talc consists essentially of pulverization and beneficiation (separation). Pulverization is accomplished using jaw crushers, roller and pebble mills. After initial pulverization, the talc is often fed into a fluid-energy mill where it is pulverized by attrition in a circular chamber in which either compressed air or steam propels the talc particles through a circular path; the finer particles leave the chamber through a central port while the coarse particles remain in the chamber (Berg 1979).

Further separation is accomplished using air classifiers, shaking tables and flotation processes. Flotation processes are used when the desired product purity is not obtained by using conventional processing; the milled ore is chemically treated, passed through rougher and cleaner cells to separate the talc from the gangue material, dried in a flash dryer and ground in a pulverizer. Ultimately the refined talc is packaged for shipment and the refuse material remains as a slurry which is transported as tailings into impoundments.

## Tailings Reclamation

The production of tailings as a waste by-product of mining operations is a world-wide phenomenon. These materials are the direct result of the beneficiation of minerals from an ore body. Mine tailings are primarily comprised of barren overburden or submarginal-grade ore extracted from open-pit or surface mines (Ludeke et al. 1974). Generally tailings are deposited in holding tanks or impoundments to minimize further disturbance to the surrounding landscape. Considering the economic constraints of the mining industry, there is no economically acceptable alternative to the present system of waste disposal (Johnson 1980). When the storage capacity of an impoundment is reached reclamation of the tailings is essential to provide an aesthetic landscape as well as to minimize the environmental effects of tailings seepage and runoff (Ritcey 1989).

Often impoundments lack vegetation because of the physicochemical limitations of the tailings material. The successful stabilization of mine tailings with vegetation is a critical step in developing a new ecosystem (Peters 1984). Vegetative stabilization is a preferred reclamation method for active and abandoned mineral-related waste sites; it is often permanent, has good aesthetics, and allows for a broad range of end uses at closure (Dean et al. 1986). Clearly a low cost, low maintenance and long term solution is desirable. As maintenance of tailings is expensive during operation of the mine, it does not make economic sense to extend this expensive care into perpetuity (Ritcey 1989).

Vegetation grown on mineral wastes can reduce wind velocity, capture dust particles, reduce raindrop impact by intercepting rainfall, reduce water runoff by improving infiltration, reduce soil dispersal and movement through aggregation, and reduce or impede overland flow of water and sediment (Norland et al. 1986). Vegetative stabilization also improves the chemical and biological characteristics of mine waste by increasing its organic matter content, nutrient supply, cation exchange capacity, and biological activity. These changes facilitate the development of healthy nutrient cycling as well as a permanent, self sustaining vegetative community.

The first consideration in reclamation planning is to select an appropriate end land use. The reclamation plan must balance desirability of end land use with tailings limitations to generate an optimal solution considering human health and safety, economics, social needs and environmental concerns (Roberts-Thorne et al. 1989). Whatever the end use, a general purpose for reclaiming mining waste sites is to stabilize them to prevent wastes from being moved by wind and water (Norland et al. 1993).

## Limiting Factors for Revegetation of Tailings

Two of the physical properties of tailings which may inhibit plant growth include the influence of hydraulic conductivity and moisture holding capacity on water availability for plants (Roberts-Thorne and Revel 1989). Properties such as thermal conductivity and surface color may also affect seed germination success and growth by influencing the temperature at seed depth (Headdon 1980). Additionally some tailings may form a strong surface crust over time which often acts to inhibit root or shoot penetration (Roberts-Thorne and Revel 1989). Furthermore, following the disuse of a tailings dam, a general lowering of the water table occurs, indicating that the natural precipitation inputs are exceeded by water losses through drainage and surface evaporation (Johnson 1980).

Absence of vegetation on tailings is due partially to low organic matter and no source of plant available nitrogen (Rutherford et al. 1982, Reeder 1990). Problems which need to be overcome before tailings can be revegetated are associated with the difference between tailings and normal soil such as lack of nutrients, unconsolidation of the surface, high reflectivity, poor aeration and low cation exchange capacity (Melis 1972). The high reflectivity of tailings necessitates the use of a fast growing companion crop, such as barley, so that the reflected heat from the tailings surface is diminished (Peters 1984).

In general, mine tailings are nutrient poor (deficient in plant nutrients), lack organic matter, lack normal microbial populations, are low in plant available water, are subject to erosion resulting in air and water quality problems and lack other physical properties (such as structure) required for sustaining a vegetative community (Norland et al. 1993, Redente and Baker 1996).

## Inorganic Fertilizers and Mulch

Studies have shown that inorganic fertilizers have been used to establish vegetation and stabilize tailings material (Norden et al. 1986, Ludeke et al. 1974). However, a major reclamation goal has been to achieve stabilization of the disturbed site with a desirable plant community that requires little or no long-term fertilization (Vodehnal 1993). To accomplish this, the physical and biological characteristics of the tailings should be characterized. The concurrent use of an organic amendment is a productive alternative to simple fertilization.

Studies have shown that surface mulches of various kinds effectively modify environmental factors to benefit plant growth (Hopkins 1955, Kay 1978, Packer and Aldon 1978, Koon and Graves 1983, McGinnies 1987, Dollhopf et al. 1989). Mulches enhance plant establishment by holding seed and fertilizer in place, retaining moisture, preventing crusting and modifying temperatures (Kay 1978). Mulches also diminish on-site erosion and increase water infiltration into the soil.

## Coversoil and Organic Amendments in Reclamation

Placing a coversoil on mine tailings has many beneficial effects upon the tailings. It provides a better medium for plant growth and it enhances fertility levels. Reclaimed mine land with topsoil has higher hydraulic conductivity, macroporosity, and drainage rates than non-topsoiled mine land (Chong et al. 1986). Topsoil application is a recommended reclamation approach because of its universally accepted advantages for vegetative establishment and success (Richmond 1989). The coversoil furnishes increased levels of organic matter for renewed microbiological activity which improves soil building processes (Packer and Aldon 1978).

Soil thickness is recognized as an important factor in determining soil quality and productivity (Power et al. 1981). Studies have shown that topsoil depth can play a significant role in the revegetation of mined lands (McGinnies and Nicholas 1980, Power et al. 1981, Redente et al. 1982, Pichtel et al. 1985, Gitt and Dollhopf 1987, Dollhopf et al. 1989, Roberts-Thorne and Revel 1989, Schuman and Taylor 1991, and Macyk 1993). However, the use of topsoil may be detrimental because disturbance of undisturbed rangeland results in a significant additional land area requiring revegetation and post reclamation management (Schuman et al. 1989). Also the deeper the soil cover, the more costly are the earthmoving operations and the greater are the impacts on soil borrow areas (Richardson 1993).

Success in revegetating mine soils may depend on the proper use and application of cultural practices and soil amendments (Vogel 1987). Amending mine spoil with organic amendments is a viable alternative to topsoil replacement (Jones and Olsen 1985). Addition of organic amendments results in the immediate improvement of the physical characteristics of mine spoils, enabling improved water infiltration and the concurrent establishment of a desirable, productive plant community (Schuman et al. 1989). Furthermore, the use of organic amendments to mitigate adverse minesoil conditions is more cost effective than borrowing topsoil from adjacent, undisturbed areas (Richmond 1989).

Mine spoils with organic amendments yield consistently higher microbial population parameter estimates than nonamended spoils (Elkins et al. 1984). The amended soil furnishes a better medium for water infiltration and retention while also providing soil structural enhancements that allow for seedling establishment. Organic amendments, such as cow manure, added to tailings also improve water holding capacity and increase nutrient availabilty through increased organic matter.

Furthermore, studies have shown that plant growth is enhanced when organic amendments are added to mine waste (Fresquez and Lindemann 1983, Norland et al. 1986, Veith and Norland 1992, Richardson 1993). In their study of lead-zinc chat tailing amended with organic residues, Norland et al. (1993) determined overall vegetative growth to be greatest with composted cattle manure, spent mushroom compost and composted yard waste and least in control plots and those amended with turkey litter. The incorporation of organic amendments to deeper depths in the profile also results in deeper penetration and yield of roots (Rowell 1977).

The theory behind adding organic residue to mining waste is that organic matter acts as a slow release fertilizer source of macro- and micro-nutrients necessary for plant nutrition and microbial growth (Veith and Norland 1992). Organic amendments are more critical in the stimulation of spoil microflora than is the addition of topsoil inoculum (Lindemann et al. 1984). Finally, organic amendments improve the water holding capacity of tailings and they provide an initial source of organic matter to aid in soil structure formation (Redente and Baker 1996).

# MATERIALS AND METHODS

## Site Description

The Barretts Minerals processing facility, the Bartlett Plant, is located in southwestern Montana on Route 15. The plant is located in the E½ Section 17, Township 8 South, Range 9 West and is 5 kilometers south of Dillon, Montana. The research area was 1.6 kilometers north of the plant on the western side of Route 15. A valley depression located on private land was filled with tailings material from the Bartlett facility. The material was approximately 6.1 meters deep in the center of the depression thinning toward the edges of the valley.

Elevation for the site is approximately 1538 meters and the average annual precipitation based on 20 years of record (Dillon, Montana airport) is 26.2 cm with an annual evaporation at the Barretts Mill complex ranging from 63.5 to 76.2 cm (Barretts Minerals, Inc. 1990). Precipitation was above normal for 1995 and normal for the first six months of 1996 (NOAA 1995 and 1996). Precipitation amounts are located in Appendix D (Tables 58 and 59). Figure 1 illustrates the location of the study site.

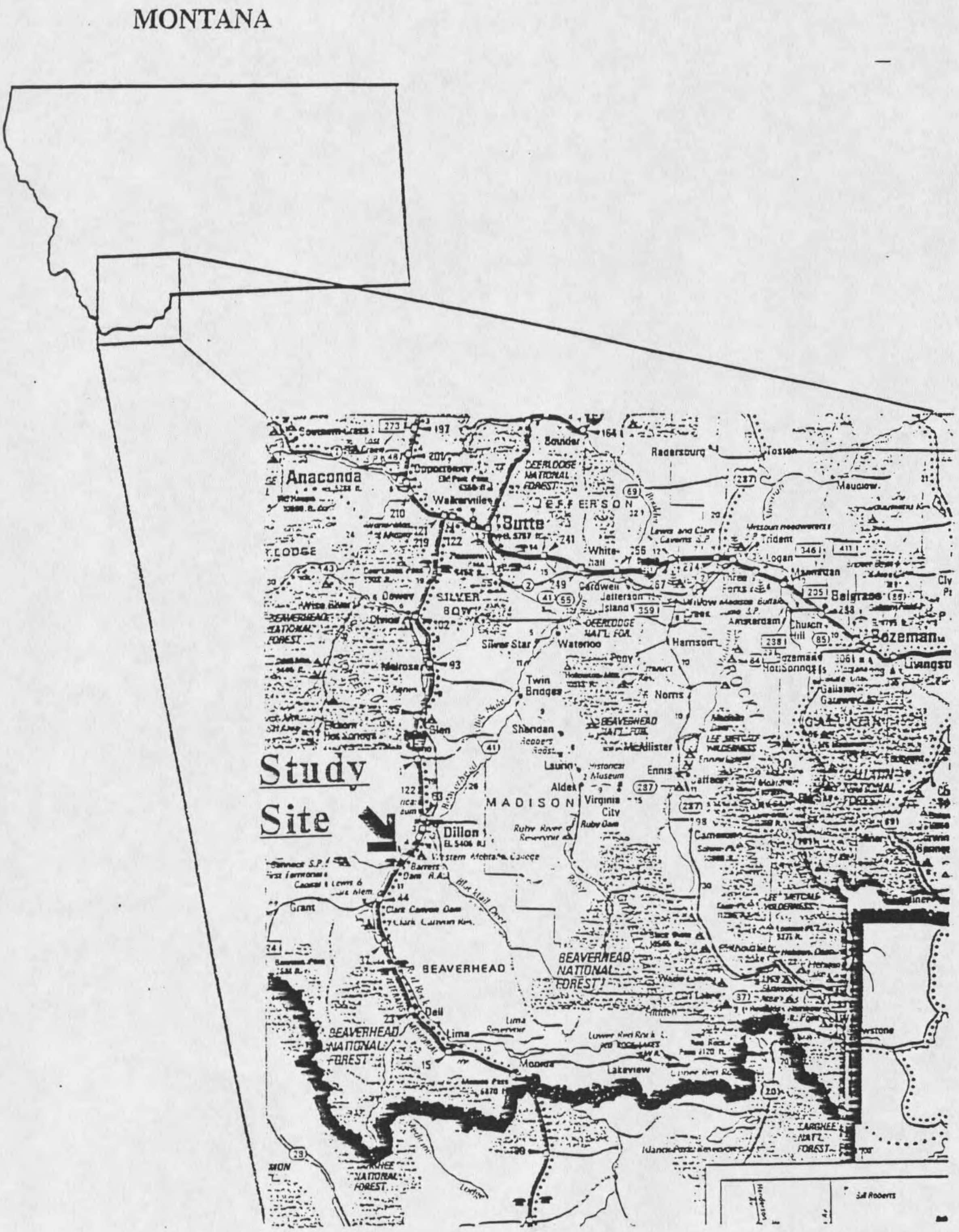



**Figure 1.** Location of tailings revegetation study site in southwestern Montana.

Field Experimental Design

Four soil treatments and a control were evaluated in a randomized complete block experimental design. The following five treatments were compared:

1. Control tilled (two passes) to 20.3 cm depth.
2. Cattle manure amendment incorporated to attain a six percent organic matter content (by dry weight) in the top 25.4 cm of the plot. The cattle manure came from a livestock yard adjacent to the Bartlett Plant. It was estimated that the tailings weighed 4480 Mg/ha/30.5 cm depth. Therefore 1995 kg of dry manure was required for a six percent organic matter content per plot. Since the manure that was applied had a gravimetric water content of 126.68%, 4523.2 kg of manure was applied to each plot.
3. 15.2 cm thick coversoil cap. This coversoil was placed into a 15.2 cm deep excavation in the tailings material.
4. 30.4 cm thick coversoil cap. This coversoil was placed in a 30.4 cm deep excavation in the tailings material.
5. 45.6 cm thick coversoil cap. This coversoil was placed into a 45.6 cm deep excavation in the tailings material.

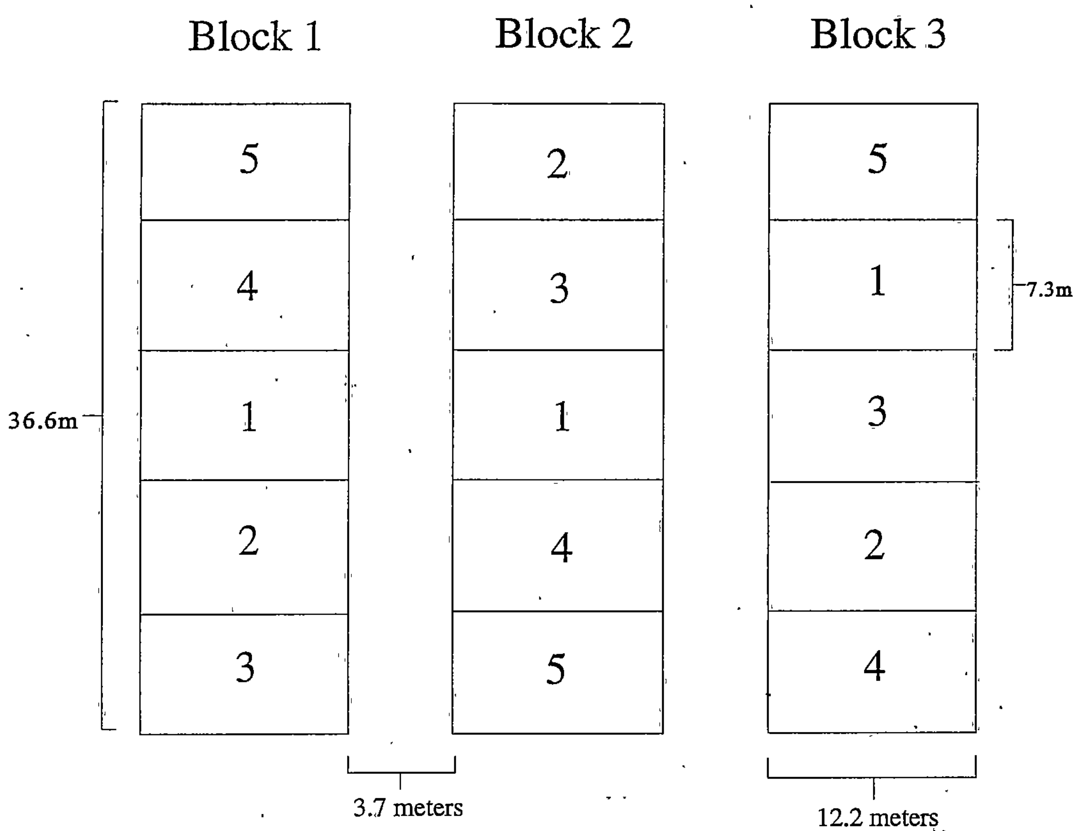



**Figure 2.** Final randomized complete block experimental plot design used on tailings at Barretts Minerals, Inc.

Because of the large machinery that was used to apply the coversoil, the actual coversoil thicknesses varied. Actual coversoil thickness data are found in Table 1.

**Table 1.** Thickness of coversoil applications to treatment plots.

| | | Coversoil Thickness (cm) | |
|---|---|---|---|
| Replication | Treatment | Designed | Actual (Mean and Standard Deviation, n = 3) |
| 1 | 3 | 15.2 | 16.9 ± 0.4 |
| 1 | 4 | 30.4 | 27.7 ± 1.3 |
| 1 | 5 | 45.6 | 43.8 ± 2.8 |
| 2 | 3 | 15.2 | 16.7 ± 1.6 |
| 2 | 4 | 30.4 | 31.1 ± 1.7 |
| 2 | 5 | 45.6 | 42.9 ± 1.3 |
| 3 | 3 | 15.2 | 17.3 ± 1.4 |
| 3 | 4 | 30.4 | 28.6 ± 2.7 |
| 3 | 5 | 45.6 | 41.7 ± 3.5 |

The application method resulted in coversoil thicknesses that were very close to the designed thicknesses. These values were deemed to be adequate for the coversoil thickness study.

## Tailings Sample Collection

Prior to plot treatment application, the experimental area was sampled in the 0-30 cm depth zone. Composite samples were taken from three equally sized subsections within each of the three blocks. Three subsamples from each subsection were composited. The composites were used for physicochemical analyses.

A coversoil composite was collected from the source area adjacent to the tailings impoundments located on the Barretts Minerals processing facility property. The soil was a fluvic inceptisol which formed naturally by alluvial deposition. The composite was gathered from the 0-5 meter deep profile of an exposed cut in the soil/parent material profile. This material was also used for physicochemical analyses.

## Tailings and Coversoil Analytical Methods

Analytical procedures used in this investigation are summarized in Table 2. All composite samples were air dried. Upon drying, the tailings and coversoil samples were disaggregated with a mortar and pestle. Materials that passed through a 2 mm sieve were used for physicochemical analyses. Materials that did not pass through the 2 mm sieve were classified as coarse fragments.

Tailings and coversoil physicochemical data are reported in Appendix A (Tables 17 - 24).

**Table 2.** Tailings and coversoil analytical methods.

| Variable | Analytical Method |
|---|---|
| pH<br>EC<br>SAR<br>Mg, Na, Ca, Cu, Fe, As, Cd, Pb, Mn, $SO_4$, Zn. | Rhoades 1982. Water saturated paste extract. |
| $NO_3$-N | Sims and Jackson 1971. Chromotropic acid extraction |
| Available-P | Olsen and Sommers 1982. Sodium bicarbonate extraction |
| K | Pratt 1965. $NH_4OAc$ extractable. |
| Particle size distribution (% sand, % silt, % clay) | Day 1965. Hydrometer method. |
| Coarse fragment content (>2mm diameter) | Dry sieve. |
| Saturation percentage | U.S. salinity laboratory staff 1954. |
| Textural class | Soil survey staff 1992. |
| Total As, Cd, Pb, Mn, Zn, Cu, Fe, Al | Test Methods for Evaluating Solid Waste, 1986. Method 3050 ($HNO_3$ and $H_2O_2$ digestion. |

## Agronomic Procedures

To prepare the seed bed, the control and coversoil treatment plots were rototilled to 20.3 cm depth and the manure treatment was rototilled to 25.4 cm depth. The agricultural rototiller made two passes over every plot except the manure treated plots which received three passes each to ensure adequate incorporation. Fertilizer was incorporated to 7.6 cm depth with a rototiller on all of the plots including the control. The fertilizer rate was 90.7 kg N/ha, 136.1 kg $P_2O_5$/ha, and 110.9 kg $K_2O$/ha. Every plot was then mulched with 4480 kg/ha of weed-free straw. The mulch was crimped into the soil. All plots were broadcast seeded after mulching on July 28, 1995. The seed mix and seed rates are presented in Table 3.

**Table 3.** Seed mix applied to all test plots.

| Species | Plant type | Pure live seed (PLS) kg/ha |
|---|---|---|
| *Agropyron riparium* | grass | 5.0 |
| *Agropyron smithii* | grass | 8.4 |
| *Agropyron spicatum* | grass | 5.0 |
| *Agropyron trachycaulum* | grass | 1.7 |
| *Elymus cinereus* | grass | 3.4 |
| *Linum perenne* | forb | 0.8 |
| *Onobrychis viciaefolia* | legume | 1.7 |
| Total | | 26.0 |

Emergence and support irrigation was conducted daily for the first two weeks after seeding and approximately every three days for an additional two weeks. Sprinklers were used and the source of water was the Beaverhead River. Plots were irrigated with approximately 1.3 cm/day of water or until water ponded on the surface. A drainage ditch and sump system was constructed around the test plot area to facilitate drainage. This ensured that the plots were not inundated during high precipitation events.

## Manure Application Rate Determination

Since treatment 2 consisted of cattle manure incorporated to attain a six percent organic matter content by dry weight in the top 25.4 cm of the plot, the water content of the manure had to be estimated. The average water content of the three composite samples of manure was 127 %. Therefore 1995.4 kg of dry manure was required for a six percent organic matter content per plot. Since the manure that was applied had an average water content of 127 %, approximately 4523.2 kg of manure was applied to each plot.

## Plant Growth Measurements

Permanent transects were set up along the diagonal of all test plots. Transects were placed one meter inside the surveyed corners of the test plots to allow for a buffer zone. Rebar was pounded into the tailings material to delineate both ends of each transect. Plant density was estimated using ten quadrats (20 x 20 cm) placed at one meter intervals in each test plot on September 16, 1995. Plant cover was estimated in ten Daubenmire frames (20 x 50 cm) also at one meter intervals on September 17, 1995 and again on July 12 and 13, 1996. Cover and density were estimated by plant type (grasses, forbs, legumes, and non-seeded species) and totaled. Production was estimated using six frames (25 x 25 cm) placed along the transect at intervals of two meters. Production samples were collected by seeded species on July 13 and 14, 1996. Species that were not seeded were placed into non-seeded grass or non-seeded forb categories.

## Statistical Analysis

Two way analysis of variance (ANOVA) statistical methods was used to analyze all data sets. Probability levels (p) less than 0.05 were considered significant. Least significant difference (LSD) was used to calculate pairwise comparisons of the means for all data sets. Four variables associated with the tailings analyses did not have normal distributions and were transformed. Reciprocals of values for the saturated paste extract of arsenic, cadmium, iron and lead were used. Within the plant measurement analyses the square root of the *Agropyron smithii* production values and the legume cover (1996) values were used. Analysis of variance tables for tailings physicochemical data and plant density, cover and production are also reported in Appendix C (Tables 46-57).

# RESULTS AND DISCUSSION

## Tailings Physicochemical Characteristics

The tailings (0 - 30 cm) had a silt loam texture and a coarse fragment content of 4.7 % (Table 4).

**Table 4.** Particle size distribution and coarse fragment content of tailings material.

| | Sand % | Silt % | Clay % | Textural class | Coarse fragments % |
|---|---|---|---|---|---|
| Mean*, n = 9 | 20 | 62 | 18 | Silt loam | 4.7 |
| St. dev.(+/-) | 8.2 | 2.9 | 6.4 | | |

* No significant differences (p = 0.05) occurred between replications.

The mean pH (7.9) and average saturation percentage (58.1%) were both suitable for plant growth. Furthermore, the electrical conductivity (1.69 mmhos/cm) and sodium adsorption ratio (0.6) mean values were both low and suitable for plant growth (Table 5).

**Table 5.** Sodium adsorption ratio (SAR), pH, saturation percentage and electrical conductivity (EC) of tailings material.

| | pH | Saturation % | EC mmhos/cm | SAR |
|---|---|---|---|---|
| Mean*, n = 9 | 7.9 | 58.1 | 1.69 | 0.6 |
| St. dev. (+/-) | 0.04 | 9.2 | 0.20 | 0.1 |

*No significant differences (p = 0.05) occurred between replications.

The mean soluble levels (saturated paste extractable) of magnesium, sodium, calcium, copper, iron, arsenic, cadmium, lead, manganese, sulfate and zinc were all low (Table 6). These values would not impair future plant growth (EPA 1987).

**Table 6.** Chemical characteristics (saturated paste extract) of the tailings material.

| | Mg | Na | Ca | Cu | Fe | As | Cd | Pb | Mn | $SO_4$ | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | | | | | | | | | | |
| Mean*,n=9 | 124 | 43 | 151 | 0.01 | 0.005 | 0.05 | 0.007 | 0.05 | 0.19 | 900 | 0.15 |
| St. dev. (+/-) | 18 | 7 | 21 | 0.01 | 0.000 | 0.00 | 0.000 | 0.00 | 0.03 | 132 | 0.20 |

*No significant differences (p = 0.05) occurred between replications.

Also the mean total levels for arsenic and the metals were all low (Table 7) and would not impair plant growth (EPA 1987).

**Table 7.** Chemical characteristics (total levels) of tailings material.

| | As | Cd | Pb | Mn | Zn | Cu | Fe | Al |
|---|---|---|---|---|---|---|---|---|
| | mg/kg | | | | | | | |
| Mean*,n=9 | 0.7 | 1.6 | 17 | 123 | 8.1# | 4.3 | 0.92 | 1.23 |
| St. dev. (+/-) | 0.3 | 0.3 | 2.5 | 17 | 0.8 | 1.2 | 0.16 | 0.14 |

*Means followed by a (#) represent composite samples that had statistically significant differences (p = 0.05) between replications.

Potassium, nitrogen as nitrate and phosphorous mean values were all low (Table 8). These fertility levels would not enhance future vegetation growth (Lichthardt et al. 1992).

**Table 8.** Nutrient content in unamended tailings material.

| | $NO_3$-N | K | P |
|---|---|---|---|
| | | mg/kg | |
| Mean*, n = 9 | 1.2 | 29# | 0.07 |
| St. dev. (+/-) | 1.1 | 7 | 0.03 |

*Means followed by a (#) represent composite samples that exhibited statistically significant differences (p = 0.05) between replications.

There were no significant differences between replications except for total zinc and potassium. These differences were not considered critical because the levels were so low that they would neither hinder nor enhance future vegetative growth. Test plots were considered homogeneous and valid statistical comparisons could be made between the experimental treatments pertaining to plant productivity.

Analysis of variance data for the tailings material are located in Appendix C (Tables 46 - 52).

## Coversoil Physicochemical Characteristics

The coversoil source had a sandy loam textural class and a coarse fragment content of 21.1% (Table 9); while the coarse fragment content was high, both of these characteristics were suitable for plant growth. The coarse fragments in the coversoil consisted primarily of fluvial gravels.

**Table 9.** Particle size distribution and coarse fragment content of coversoil material.

| | Sand % | Silt % | Clay % | Textural Class | Coarse fragments % |
|---|---|---|---|---|---|
| Measured value n = 1 | 59 | 29 | 12 | Sandy loam | 21.1 |

The pH (7.8) as well as the saturation percentage (47.9 %) were suitable values for plant growth. Coversoil sodicity was low (0.8) while the electrical conductivity was slightly elevated (3.72) but suitable for plant growth (Table 10).

**Table 10.** Sodium adsorption ratio (SAR), pH, saturation percentage and electrical conductivity (EC) of coversoil material.

| | pH | Saturation % | EC mmhos/cm | SAR |
|---|---|---|---|---|
| Measured value n = 1 | 7.8 | 47.9 | 3.72 | 0.8 |

Soluble levels of magnesium, sodium, calcium, copper, iron, arsenic, cadmium, lead, manganese, sulfate and zinc were all low and therefore suitable for plant growth (Table 11).

**Table 11.** Chemical characteristics (saturated paste extract) of coversoil material.

| | Mg | Na | Ca | Cu | Fe | As | Cd | Pb | Mn | $SO_4$ | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | | | | | | | | | | |
| Measured value, n = 1 | 151 | 76 | 475 | 0.15 | 0.23 | <0.1 | 0.06 | <0.1 | 0.50 | 189 | 0.44 |

The total levels of arsenic and metals were low and suitable for plant growth (Table 12).

**Table 12.** Chemical characteristics (total levels) of coversoil material.

| | As | Cd | Pb | Mn | Zn | Cu | Fe | Al |
|---|---|---|---|---|---|---|---|---|
| | | | | mg/kg | | | | |
| Measured value, n = 1 | 5.1 | 2.5 | 23 | 375 | 49.9 | 12.4 | 1.25 | 1.32 |

Unusually high levels of potassium, nitrate-nitrogen and phosphorous were present in the coversoil (Table 13) (Lichthardt et al. 1992). The source of these nutrients was not

**Table 13.** Nutrient content in coversoil material.

| | $NO_3$-N | K | P |
|---|---|---|---|
| | | mg/kg | |
| Measured value n = 1 | 704 | 176.2 | 62.8 |

apparent. However, prior agronomic practices or flood deposition may have caused the elevated nutrient levels. However, these fertility levels are not phytotoxic to plants (Munshower 1992). The same amount of fertilizer was used on all of the plots so that macronutrient levels were not a limiting factor to future plant growth.

Plant Density After the First Growing Season (1995)

Since measurements were obtained only 1.5 months after seeding, plant species were not identifiable. Therefore, density measurements were grouped into plant type categories. These categories were grasses, forbs, legumes, perennial grasses, nonseeded species and total plant density. There were no significant differences between treatments for perennial grass, nonseeded species and total plant density measurements (Table 14). However, the 45.6 cm coversoil application exhibited greater forb density than both the control and the manure, yet it was not greater than either the 15.2 cm or 30.4 cm coversoil treatments. The mean forb density was not different between the control and manure

**Table 14.** Plant density (plants/$m^2$) by plant type and tailings treatment 1.5 months after seeding in 1995.

| | Treatment | | | | |
|---|---|---|---|---|---|
| | | | Coversoil | | |
| Plant type | Control | Manure | 15.2 cm | 30.4 cm | 45.6 cm |
| Mean perennial* grass density | 165.0 a# | 195.0 a | 205.0 a | 157.5 a | 227.5 a |
| Mean forb density | 17.5 a | 7.5 a | 42.5 ab | 45.0 ab | 92.5 b |
| Mean legume density | 8.3 b | 1.5 a | 11.7 b | 6.7 ab | 10.7 b |
| Mean nonseeded species density | 2.5 a | 0.0 a | 10.0 a | 10.0 a | 25.0 a |
| Total vegetation density | 192.5 a | 205.0 a | 267.5 a | 220.0 a | 355.0 a |

*Table values are a mean of 3 replications for each treatment (10 observations per plot).
#Means in the same row followed by the same letter are not significantly different ($p = 0.05$).

treatment. While the 15.2 cm and the 45.6 cm coversoil treatments had greater legume density values than the manure treatment, they did not significantly differ from the control.

Initial indications suggested that forb and legume density (1995) were higher on some coversoil treatments than on the manure. It was likely that plant propagules present in the coversoil source contributed to this result. These propagules were apparently well suited to the conditions of the site and therefore established quickly.

First year plant density is indicated in Appendix B (Tables 29-32). Analysis of variance data for first year plant density is in Appendix C (Table 54).

## Plant Cover After the First Growing Season (1995)

First year plant cover measurements were also grouped into the same plant type categories used for plant density. There were no significant differences between the treatments for perennial grasses, forb, legume or total plant cover (Table 15). However, the 45.6 cm coversoil treatment had greater nonseeded species cover than both the manure treatment and the control.

No clear results were apparent from the first year vegetative data. First year cover data suggested that more nonseeded species invaded the thickest coversoil application than the control and manure treatment. Again, plant propagules present in the coversoil source was the likely cause. However, first year data should be interpreted with caution because of the short time span between seeding date and data collection.

**Table 15.** Plant cover (%) by plant type and tailings treatment 1.5 months after seeding in 1995.

| | Treatment | | | | |
|---|---|---|---|---|---|
| | | | Coversoil | | |
| Plant type | Control | Manure | 15.2 cm | 30.4 cm | 45.6 cm |
| Mean perennial* grass cover | 26 a # | 19 a | 28 a | 21 a | 30 a |
| Mean forb cover | 1 a | 1 a | 2 a | 1 a | 3 a |
| Mean legume cover | 1 a | 0 a | 1 a | 1 a | 1 a |
| Mean nonseeded species cover | 1 a | 0 a | 4 ab | 4 ab | 9 b |
| Total vegetation cover | 28 a | 22 a | 35 a | 28 a | 42 a |

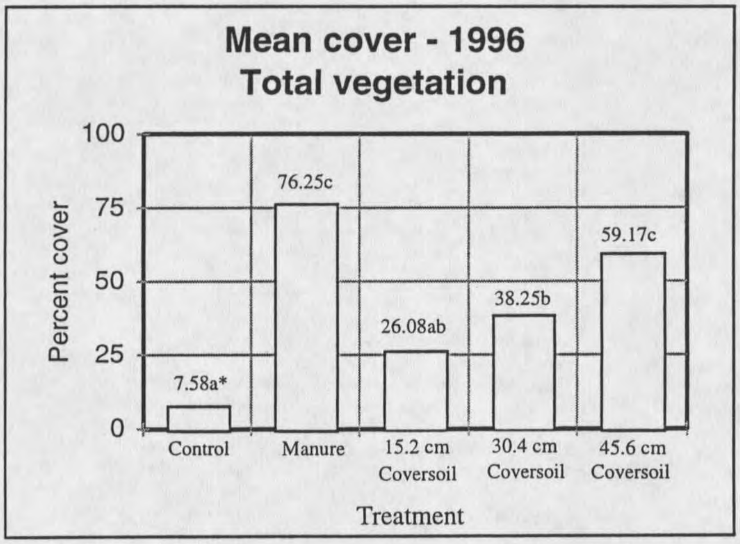
*Table values are a mean of 3 replications for each treatment (10 observations per plot).
#Means in the same row followed by the same letter are not significantly different ($p = 0.05$).

Data for first year plant cover is in Appendix B (Tables 25 - 28). Analysis of variance for first year plant cover is in Appendix C (Table 55).

Plant Cover After the Second Growing Season (1996)

For total vegetation cover the 15.2 cm coversoil treatment did not significantly differ from the control or the 30.4 cm treatment; however, the 30.4 cm treatment had a significantly greater mean total plant cover value than the control (Figure 3). The manure and the 45.6 cm coversoil treatment were not significantly different for total plant cover; they both had significantly greater values than the control, 15.2 cm and 30.4

cm coversoil treatments. The increased organic matter and the enhanced growing medium resulted in greater vegetative growth.




[+]Graph values are a mean of 3 replications for each treatment (10 observations per plot).
*Means followed by the same letter are not significantly different ($p = 0.05$).

**Figure 3.** Mean total vegetation cover (%) after the second growing season (1996).

The manure treatment had greater perennial grass cover than all of the other treatments (Figure 4). Presumably enhanced organic matter and nutrients contributed by the manure augmented plant growth on the tailings. The manure may also have improved the structural limitations inherent in the tailings by improving aeration, augmenting aggregation, enhancing the water holding capacity, providing a better medium for root penetration and improving cation exchange capacity (Soil Improvement Committee 1985).

Seeded forb cover results are in Figure 5 and legume cover results are in Figure 6.

The enhanced nutrient levels in the coversoil potentially contributed to the results in these two categories.

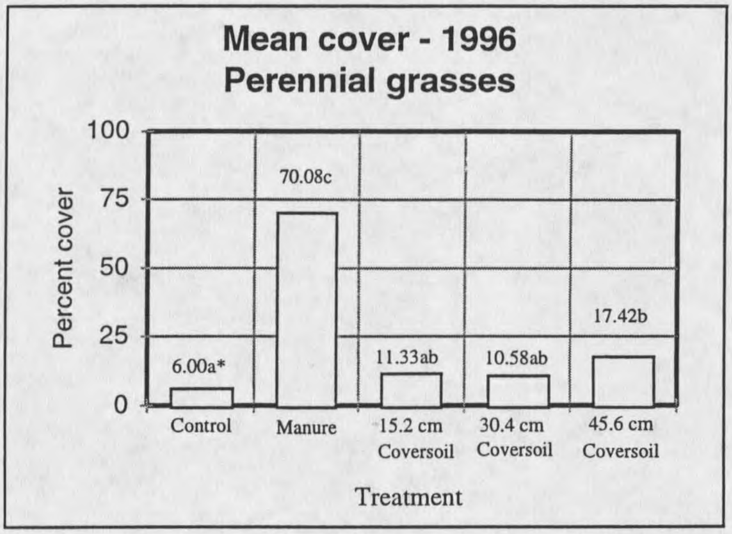
There were no differences between the control, manure treatment and 15.2 cm coversoil treatment for nonseeded species cover (Figure 7). The 45.6 cm coversoil treatment showed greater nonseeded species cover than the control, manure, and 15.2 cm coversoil treatments, but it did not differ from the 30.4 cm treatment. Plant propagules present within the coversoil were the likely cause of this result.

Data for second year plant cover is in Appendix B (Tables 33 - 36). Analysis of variance for second year plant cover is in Appendix C (Table 56).

Plant Production After the Second Growing Season (1996)

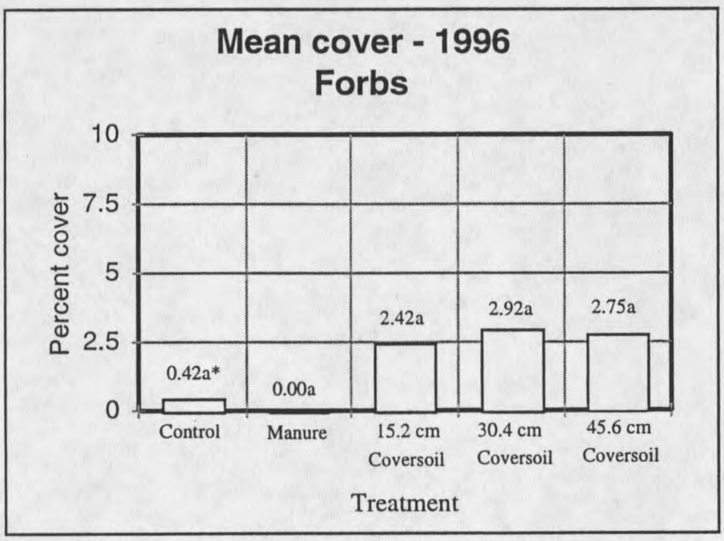
Production measurements were grouped according to seeded species with additional categories of nonseeded forbs, nonseeded grasses, total seeded grasses and total vegetation production. The 45.6 cm coversoil treatment had greater total vegetation production than the control, 15.2 cm and 30.4 cm coversoil treatments. However, the manure treatment was greater than all of the treatments (Figure 8). No differences were found between the control, 15.2, 30.4 and 45.6 cm coversoil treatments for total seeded grass production. However, the manure treatment was greater than all of the other treatments (Figure 9) presumably because of the increased organic matter and nutrients as well as the enhanced structural characteristics of the tailings.

There were no differences between the coversoil treatments and the control for *Agropyron spicatum*, *Agropyron smithii*, or *Agropyron trachycaulum*; however, the



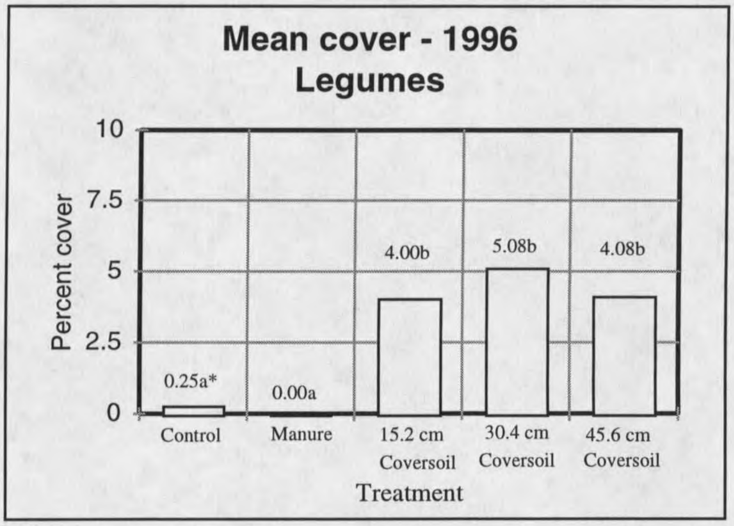

+Graph values are a mean of 3 replications for each treatment (10 observations per plot).
*Means followed by the same letter are not significantly different (p = 0.05).

**Figure 4.** Mean perennial grass cover (%) after the second growing season (1996).



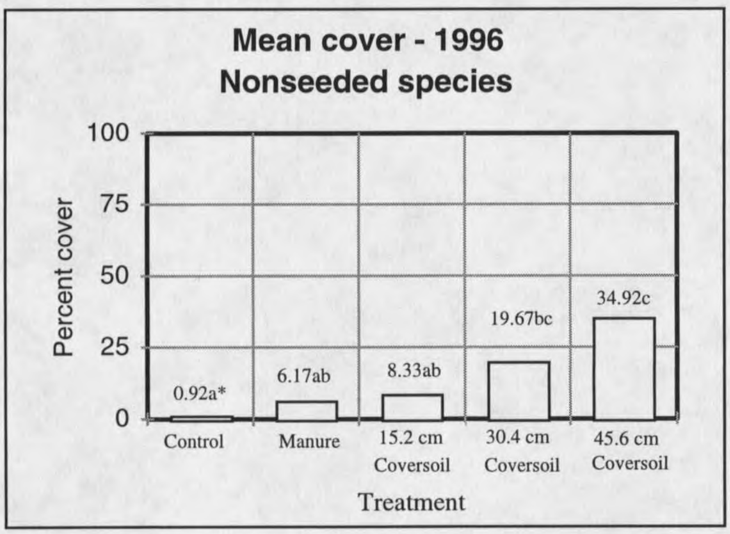

+Graph values are a mean of 3 replications for each treatment (10 observations per plot).
*Means followed by the same letter are not significantly different (p = 0.05).

**Figure 5.** Mean forb cover (%) after the second growing season (1996).



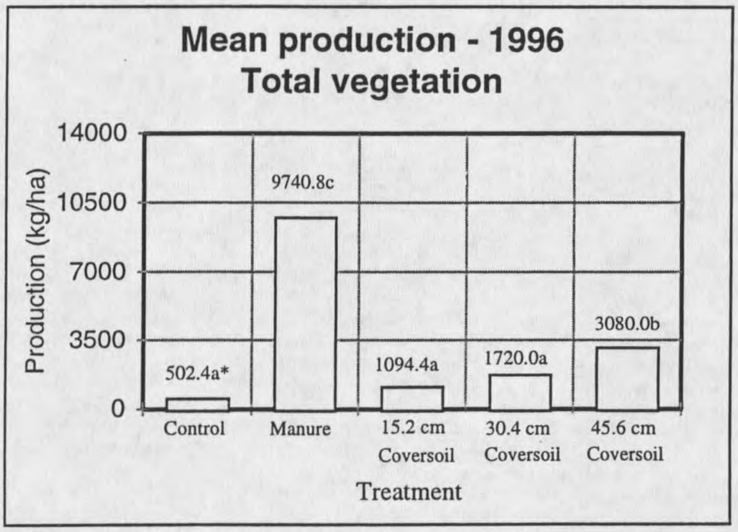

+Graph values are a mean of 3 replications for each treatment(10 observations per plot).
*Means followed by the same letter are not significantly different (p = 0.05).

**Figure 6.** Mean legume cover (%) after the second growing season (1996).



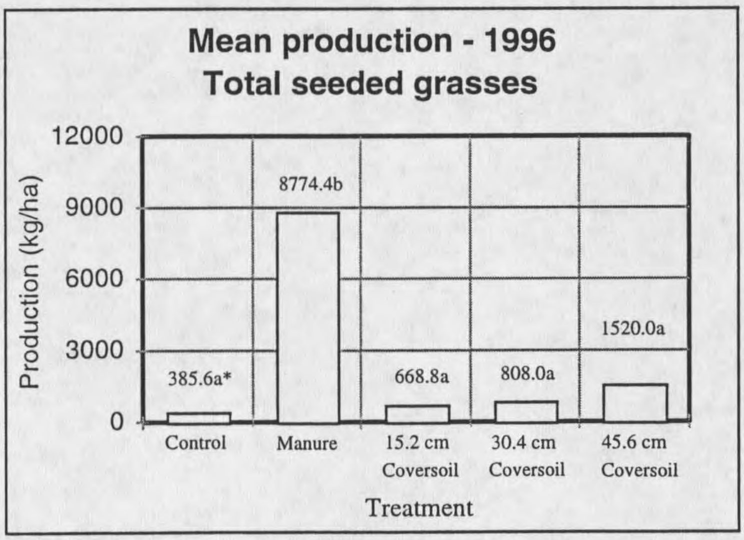

+Graph values are a mean of 3 replications for each treatment (10 observations per plot).
*Means followed by the same letter are not significantly different (p = 0.05).

**Figure 7.** Mean nonseeded species cover (%) after the second growing season (1996).




+Graph values are a mean of 3 replications for each treatments (6 observations per plot).
*Means followed by the same letter are not significantly different (p = 0.05).

**Figure 8.** Mean production (kg/ha) for total vegetation after the second growing season (1996).




+Graph values are a mean of 3 replications for each treatment (6 observations per plot).
*Means followed by the same letter are not significantly different (p = 0.05).

**Figure 9.** Mean production (kg/ha) for total seeded grasses after the second growing season (1996).

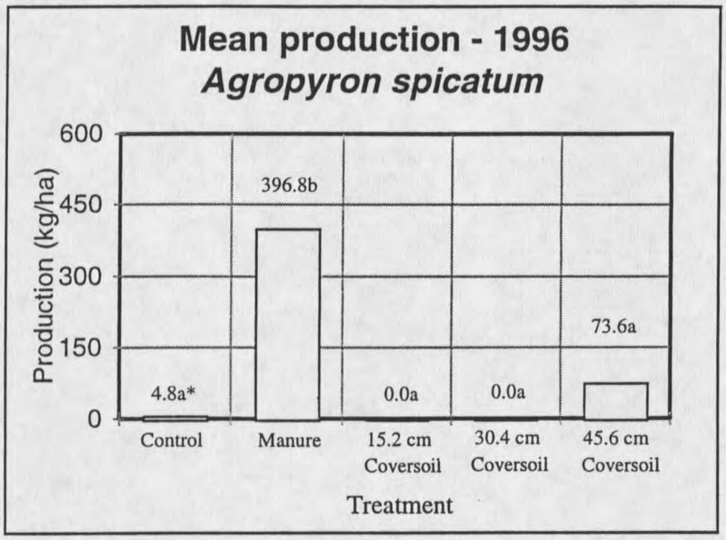
manure treatment had greater production than all of the coversoil treatments and the control for each of these species (Figures 10, 11 and 12).

*Onobrychis viciaefolia* production results are in Figure 13 and Linum perenne results are in Figure 14. *Onobrychis viciaefolia* and *Linum perenne* had greater production on the coversoil treatments than the control because the growing medium was better and organic matter content was higher. Also these species did not do well on the manure treated plots because the grasses simply outcompeted these species for plant available water.

There were no differences between any of the treatments and the control for nonseeded grasses. On the other hand, the 45.6 cm coversoil treatment had greater production for nonseeded forbs than all of the other treatments as well as the control (Figure 15). Concurrently the control, 15.2 cm, 30.4 cm and manure treatments did not differ.

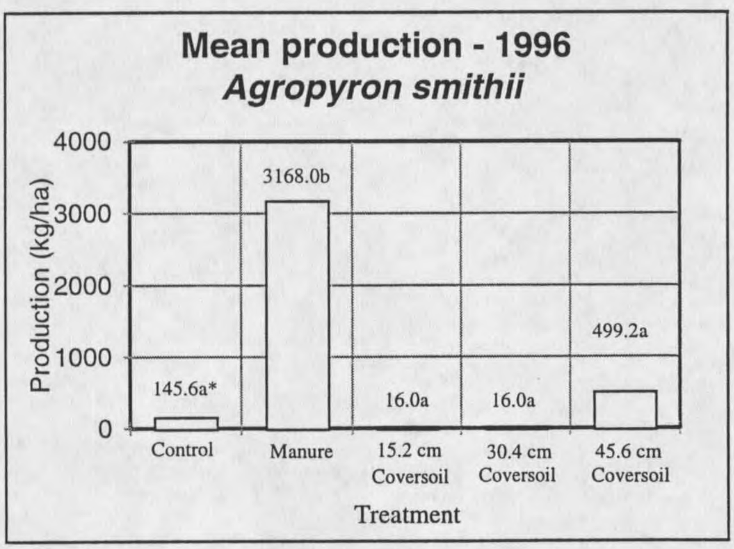
Data for second year plant production is in Appendix B (Tables 37-45). ANOVA results for second year plant production is in Appendix C (Tables 53 and 57).

There were significant block differences for forb cover (1995), legume density and nonseeded species cover (1995). Since significant block differences were detected for first year data only, it was believed that these differences resulted from the short time span (one and a half months) between seeding date and data collection.



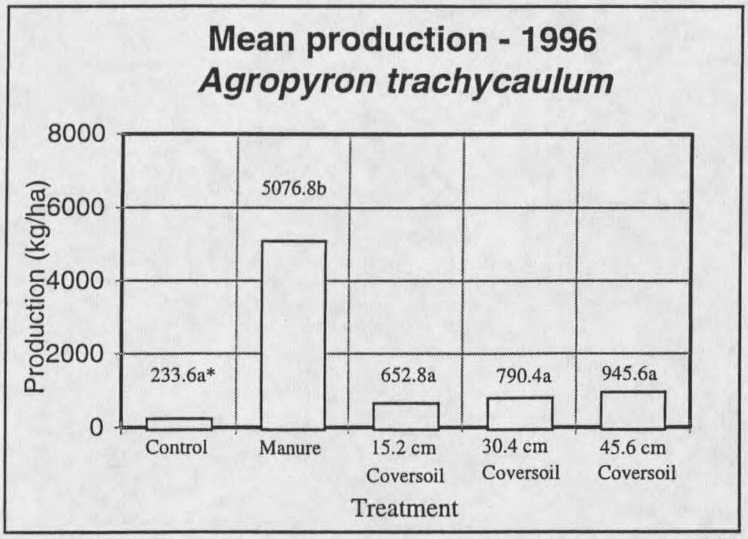

+Graph values are a mean of 3 replications for each treatment (6 observations per plot).
*Means followed by the same letter are not significantly different ($p = 0.05$).

**Figure 10.** Mean production (kg/ha) for *Agropyron spicatum* (bluebunch wheatgrass) after the second growing season (1996).



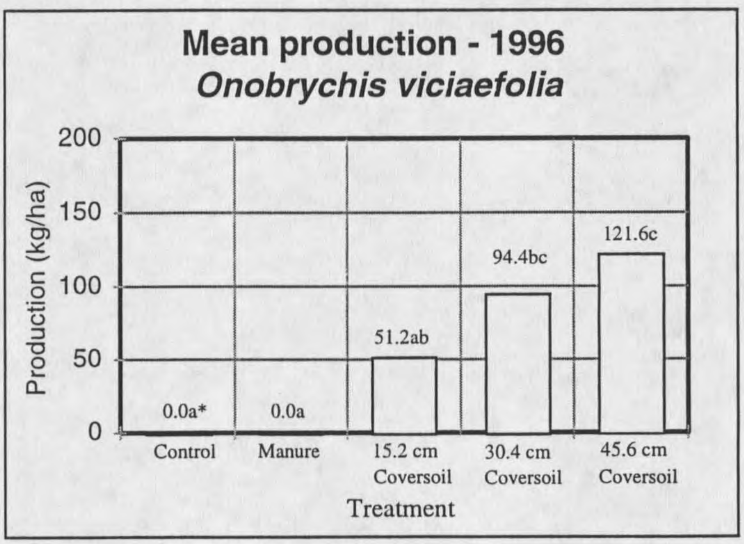

+Graph values are a mean of 3 replications for each treatment (6 observations per plot).
*Means followed by the same letter are not significantly different ($p = 0.05$).

**Figure 11.** Mean production (kg/ha) for *Agropyron smithii* (western wheatgrass) after the second growing season (1996).



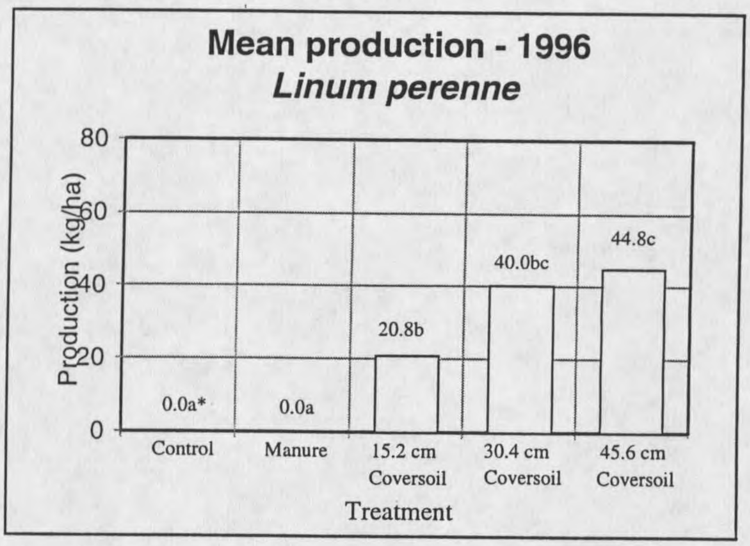

⁺Graph values are a mean of 3 replications for each treatment (6 observations per plot).
*Means followed by the same letter are not significantly different (p = 0.05).

**Figure 12.** Mean production (kg/ha) for *Agropyron trachycaulum* (slender wheatgrass) after the second growing season (1996).



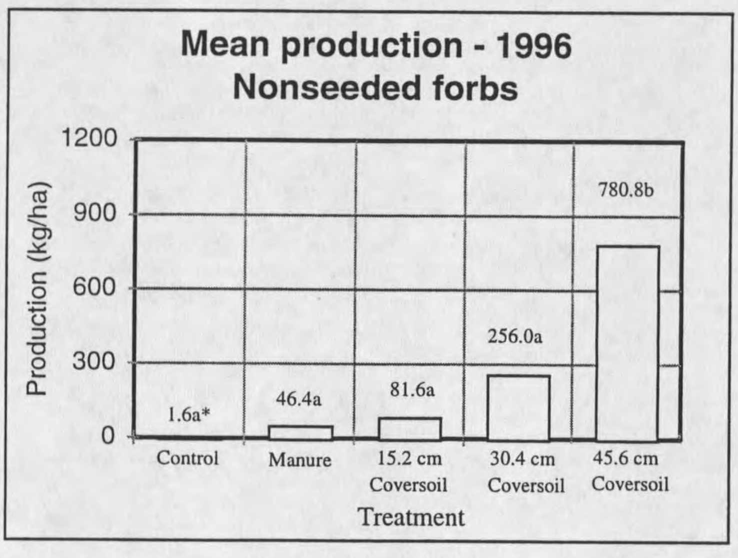

⁺Graph values are a mean of 3 replications for each treatment (6 observations per plot).
*Means followed by the same letter are not significantly different (p = 0.05).

**Figure 13.** Mean production (kg/ha) for *Onobrychis viciaefolia* (sanfoin) after the second growing season (1996).




[+]Graph values are a mean of 3 replications for each treatment (6 observations per plot).
*Means followed by the same letter are not significantly different (p = 0.05).

**Figure 14.** Mean production (kg/ha) for *Linum perenne* (blue flax) after the second growing season (1996).




[+]Graph values are a mean of 3 replications for each treatment (6 observations per plot).
*Means followed by the same letter are not significantly different (p = 0.05).

**Figure 15.** Mean production (kg/ha) for nonseeded forbs after the second growing season (1996).

## Tailings Management

Tailings produced from talc processing are relatively innocuous materials because of the inherent absence of acid producing materials and low metal, sodicity and salinity levels. However, there are factors that inhibit vegetation growth because talc tailings do not sustain a natural and healthy plant community. The main conditions contributing to inadequate vegetation growth are apparently associated with structural characteristics of the tailings and nutrient deficiencies. The tailings typically exhibit a massive structure devoid of aggregation. Also, as was discovered through laboratory analyses, these materials do not have adequate nutrient levels for sustained plant growth. The ability of mine waste to retain plant nutrients is low and there is rapid leaching of applied water soluble fertilizer from the plant root zone; however, this varies with physical properties and the site specific water balance (Archer 1985). Furthermore, without vegetation, organic matter will not accumulate and adequate nutrient cycling will not develop. Organic matter content for tailings is usually below 1% (Fox 1984). Although coversoil applications did enhance the capacity for the tailings to sustain plant growth, an amendment of cow manure exhibited the greatest promise for talc tailings reclamation.

One potential shortcoming of the manure treatment is that the legume and forb species did not perform well on this treatment. The coversoil applications generally supported greater numbers of forbs and legumes than the manure treated plots. While this suggests a lack of diversity on the manure amended plots, there were consistently four to six grasses on each of the manure treated plots. This resulted from the invasion of some nonseeded grasses. Furthermore, the impressive growth of grasses on the manure amended plots likely prevented the establishment of legumes and forbs meaning the grasses preempted resources. Also, many of the forb species present on the coversoil plots were invasive and weedy species that possessed little grazing or even aesthetic value. The manure amended plots on the other hand were virtually free of these undesirable species.

*Agropyron spicatum*, *Agropyron smithii*, and *Agropyron trachycaulum* grew well on the manure treated plots and therefore should be considered when reclaiming talc tailings with a manure amendment. The seeded species *Agropyron riparium* did not grow in any of the test plots. This particular species may have been outcompeted by other grass species. While *Elymus cinereus* was found on only two plots, these plots were both manure treated plots. Therefore *Elymus cinereus* could be considered as a potential seeded species when reclaiming talc tailings with manure.

Manure appears to be an excellent amendment for talc tailings reclamation. It enhances the structural characteristics of the tailings material. The root structure of grasses also binds tailings together and starts the natural process whereby the tailings will become a soil (Melis 1972). Ultimately the vegetation that established on the manure treated plots should enhance the development of healthy nutrient cycling on the tailings material.

# SUMMARY AND CONCLUSIONS

A field experiment at the Barretts Minerals Incorporated processing plant in southwest Montana was initiated to assess plant response on amended talc tailings. The tailings were not saline, sodic, acidic or toxic in nature. Their structureless physical condition and low plant nutrient status precluded plant growth. Therefore, the objectives of this study were to identify the tailings physicochemical properties that limit plant establishment and growth, evaluate plant productivity on talc tailings amended with manure and coversoil, and recommend a revegetation plan for talc tailings.

A randomized complete block experimental design was implemented consisting of three blocks and five plots per block. The treatments consisted of cattle manure incorporated into the tailings to attain a six percent organic matter content by dry weight, three varying thicknesses (15.2 cm, 30.4 cm and 45.6 cm) of coversoil placed into excavations in the tailings and a control. All plots were fertilized with 90.7 kg N/ha, 136.1 kg $P_2O_5$/ha, and 110.9 kg $K_2O$/ha. Vegetation response was analyzed using two way analysis of variance (ANOVA) for a blocked design.

After two growing seasons the 45.6 cm coversoil application had significantly greater total vegetation cover and production than the other coversoil treatments as well as the control. However, it did not differ from the manure for total vegetation cover. Furthermore, the manure treated plots had significantly greater perennial grass cover and total vegetation production than all other treatments. The manure treatment also had significantly greater production than the other treatments for *Agropyron spicatum*, *Agropyron smithii*, *Agropyron trachycaulum*, and total seeded grasses. The results from this study suggest that manure is an excellent amendment for talc tailings reclamation.

Manure is also a low cost alternative compared to coversoil application. The lower expense results because the manure treatment requires less haulage than coversoil. A soil that has a bulk density of 1.47 $g/cm^3$ weighs approximately 6,726,000 kg/ha/45.6 cm depth. On the other hand, the weight of manure required for a six percent organic matter content (dry weight) to a 25.4 cm depth weighs 224,200 kg/ha. Since the manure in this study had a water content of 127%, the final weight of manure would be 284,730 kg/ha/25.4 cm depth. The manure would also require more haulage per unit mass than coversoil because of its lower bulk density; however, the cost of handling the manure will be notably less than for coversoil.

The recommended talc tailings revegetation plan for Barretts Minerals Incorporated is located in Table 16. While the tailings may require additional fertilization, vegetation that establishes on the manure treated tailings should facilitate the establishment of nutrient cycling and a sustainable plant community. However, Barretts Minerals, Inc. should conduct long term monitoring to ascertain that the plant community continues to develop and stabilize the site.

**Table 16.** Recommended tailings revegetation specifications for Barretts Minerals, Inc.

| | |
|---|---|
| Treatment | Cattle manure incorporated to attain a six percent organic matter content (dry weight) in the 0 - 25.4 cm depth increment of the tailings. |
| Fertilizer rate | 90.7 kg N/ha, 136.1 kg $P_2O_5$/ha, and 110.9 kg $K_2O$/ha. Broadcast application. |
| Seeded species and seed rate (PLS) | *Agropyron spicatum* (bluebunch wheatgrass) - 5.0 kg/ha<br>*Agropyron smithii* (western wheatgrass) - 8.4 kg/ha<br>*Agropyron trachycaulum* (slender wheatgrass) - 1.7 kg/ha<br>*Elymus cinereus* (great basin wildrye) - 3.4 kg/ha |
| Agronomic practices | 1. Rototill manure (three passes) into tailings material<br>2. Mulch with 4480 kg/ha of weed-free straw.<br>3. Crimp the mulch into the tailings.<br>4. Broadcast seed after mulching. |
| Maintenance | Construct to facilitate drainage.<br>Fertilize as needed. |

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# APPENDICES

# APPENDIX A

## TAILINGS AND COVERSOIL PHYSICOCHEMICAL DATA

**Table 17.** Tailings physicochemical analyses - saturated paste (mg/L).

| Sample | Mg | Na | Ca | Cu | Fe | As | Cd | Pb | Mn | Zn | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 156 | 53 | 172 | <.01 | <.01 | <.1 | <.01 | <.1 | 0.23 | 0.03 | 1077 |
| 2 | 139 | 43 | 158 | <.01 | <.01 | <.1 | <.01 | <.1 | 0.19 | 0.11 | 1019 |
| 3 | 113 | 36 | 121 | <.01 | <.01 | <.1 | <.01 | <.1 | 0.21 | 0.14 | 792 |
| 4 | 105 | 45 | 136 | <.01 | <.01 | <.1 | <.01 | <.1 | 0.17 | 0.48 | 758 |
| 5 | 124 | 40 | 147 | <.01 | <.01 | <.1 | <.01 | <.1 | 0.17 | 0.04 | 937 |
| 6 | 138 | 50 | 183 | 0.01 | <.01 | <.1 | <.01 | <.1 | 0.22 | 0.04 | 1046 |
| 7 | 130 | 34 | 171 | 0.02 | <.01 | <.1 | 0.01 | <.1 | 0.15 | <.01 | 939 |
| 8 | 101 | 47 | 136 | 0.02 | <.01 | <.1 | 0.01 | <.1 | 0.15 | <.01 | 753 |
| 9 | 114 | 35 | 136 | 0.02 | <.01 | <.1 | 0.01 | <.1 | 0.22 | 0.49 | 777 |

**Table 18.** Coversoil physicochemical analyses - saturated paste (mg/L).

| Sample | Mg | Na | Ca | Cu | Fe | As | Cd | Pb | Mn | Zn | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 151 | 76 | 475 | 0.15 | 0.23 | <.1 | 0.06 | <.1 | 0.50 | 0.44 | 189 |

**Table 19.** Tailings physicochemical analyses - digest (mg/kg for all except Fe and Al which are recorded as %).

| Sample | Zn | As | Cd | Cu | Fe | Mn | Al | Pb |
|---|---|---|---|---|---|---|---|---|
| 1 | 8.5 | 0.7 | 1.6 | 5.6 | 0.847 | 119 | 1.18 | 17 |
| 2 | 7.7 | 0.6 | 1.5 | 3.9 | 0.901 | 118 | 1.22 | 18 |
| 3 | 9.4 | 1.1 | 1.6 | 6.8 | 0.912 | 129 | 1.24 | 18 |
| 4 | 7.3 | 0.2 | 1.2 | 3.0 | 0.794 | 111 | 1.11 | 16 |
| 5 | 7.7 | 0.8 | 1.6 | 4.5 | 0.909 | 117 | 1.24 | 17 |
| 6 | 8.4 | 0.7 | 1.6 | 3.8 | 0.896 | 126 | 1.23 | 15 |
| 7 | 8.2 | 0.7 | 1.6 | 3.5 | 0.932 | 124 | 1.21 | 15 |
| 8 | 7.0 | 0.6 | 1.3 | 3.2 | 0.758 | 102 | 1.08 | 12 |
| 9 | 8.9 | 1.0 | 2.3 | 4.3 | 1.318 | 164 | 1.57 | 21 |

**Table 20.** Coversoil physicochemical analyses - digest (mg/kg for all except Fe and Al which are recorded as %).

| Sample | Zn | As | Cd | Cu | Fe | Mn | Al | Pb |
|---|---|---|---|---|---|---|---|---|
| 1 | 49.9 | 5.1 | 2.5 | 12.4 | 1.246 | 375 | 1.32 | 23 |

**Table 21.** Tailings physicochemical analyses.

| Sample | K (mg/kg) | EC (mmhos/cm) | Sand (%) | Silt (%) | Clay (%) | $NO_3$-N (mg/kg) | P (mg/kg) |
|---|---|---|---|---|---|---|---|
| 1 | 26 | 1.97 | 16 | 63 | 21 | 1.7 | 0.2 |
| 2 | 24 | 1.77 | 15 | 61 | 24 | 1.9 | <.1 |
| 3 | 32 | 1.47 | 15 | 61 | 24 | 2.0 | <.1 |
| 4 | 24 | 1.53 | 17 | 65 | 18 | 3.2 | <.1 |
| 5 | 24 | 1.67 | 14 | 62 | 24 | 0.2 | <.1 |
| 6 | 38 | 1.94 | 17 | 63 | 20 | 1.1 | <.1 |
| 7 | 24 | 1.74 | 31 | 57 | 12 | 0.2 | <.1 |
| 8 | 26 | 1.53 | 18 | 66 | 16 | 0.2 | <.1 |
| 9 | 44 | 1.56 | 37 | 58 | 5 | 0.4 | <.1 |

**Table 22.** Coversoil physicochemical analyses.

| Sample | K (mg/kg) | EC (mmhos/cm) | Sand (%) | Silt (%) | Clay (%) | $NO_3$-N (mg/kg) | P (mg/kg) |
|---|---|---|---|---|---|---|---|
| 1 | 704 | 3.72 | 59 | 29 | 12 | 176.2 | 62.8 |

**Table 23.** Tailings physicochemical analyses.

| Sample | pH | SAR | $\%H_2O$ | Texture |
|---|---|---|---|---|
| 1 | 7.9 | 0.7 | 62.6 | silt loam |
| 2 | 7.9 | 0.6 | 64.9 | silt loam |
| 3 | 8.0 | 0.6 | 64.6 | silt loam |
| 4 | 7.9 | 0.7 | 63.0 | silt loam |
| 5 | 7.9 | 0.6 | 65.4 | silt loam |
| 6 | 7.9 | 0.7 | 60.2 | silt loam |
| 7 | 7.9 | 0.5 | 47.7 | silt loam |
| 8 | 7.9 | 0.8 | 55.9 | silt loam |
| 9 | 8.0 | 0.5 | 38.9 | silt loam |

**Table 24.** Coversoil physicochemical analyses.

| Sample | pH | SAR | $\%H_2O$ | Texture |
|---|---|---|---|---|
| 1 | 7.8 | 0.8 | 47.9 | sandy loam |

# APPENDIX B

# VEGETATION DATA

**Table 25.** Perennial grass cover (%) in August 1995.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 2.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 15 | 15 | 37.5 | 15 |
| 1 | 2 | 37.5 | 37.5 | 15 | 37.5 | 15 | 37.5 | 37.5 | 2.5 | 2.5 | 15 |
| 1 | 3 | 2.5 | 2.5 | 15 | 15 | 15 | 2.5 | 2.5 | 15 | 15 | 15 |
| 1 | 4 | 37.5 | 37.5 | 37.5 | 15 | 37.5 | 37.5 | 15 | 15 | 15 | 37.5 |
| 1 | 5 | 85 | 37.5 | 37.5 | 15 | 37.5 | 62.5 | 62.5 | 37.5 | 15 | 62.5 |
| 2 | 1 | 37.5 | 15 | 37.5 | 37.5 | 2.5 | 2.5 | 0 | 2.5 | 0 | 0 |
| 2 | 2 | 62.5 | 62.5 | 62.5 | 37.5 | 37.5 | 37.5 | 15 | 15 | 15 | 15 |
| 2 | 3 | 2.5 | 2.5 | 2.5 | 37.5 | 15 | 15 | 15 | 37.5 | 15 | 15 |
| 2 | 4 | 2.5 | 2.5 | 0 | 0 | 2.5 | 2.5 | 37.5 | 15 | 15 | 62.5 |
| 2 | 5 | 37.5 | 15 | 15 | 15 | 37.5 | 2.5 | 37.5 | 15 | 37.5 | 37.5 |
| 3 | 1 | 62.5 | 37.5 | 15 | 37.5 | 15 | 37.5 | 62.5 | 37.5 | 37.5 | 37.5 |
| 3 | 2 | 15 | 15 | 62.5 | 15 | 37.5 | 37.5 | 15 | 37.5 | 2.5 | 15 |
| 3 | 3 | 37.5 | 15 | 62.5 | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | 15 | 15 |
| 3 | 4 | 15 | 15 | 37.5 | 37.5 | 15 | 15 | 37.5 | 15 | 15 | 15 |
| 3 | 5 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 62.5 | 15 | 15 |

**Table 26.** Legume cover (%) in August 1995.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 0 | 2.5 | 2.5 | 0 | 0 |
| 1 | 2 | 0 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 0 | 2.5 | 2.5 |
| 1 | 3 | 0 | 0 | 0 | 2.5 | 0 | 0 | 2.5 | 2.5 | 0 | 2.5 |
| 1 | 4 | 0 | 0 | 2.5 | 2.5 | 0 | 2.5 | 2.5 | 0 | 0 | 0 |
| 1 | 5 | 0 | 2.5 | 2.5 | 0 | 0 | 0 | 0 | 0 | 2.5 | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 0 | 0 | 0 | 0 | 2.5 | 2.5 | 0 | 0 | 0 | 0 |
| 2 | 3 | 0 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 | 0 | 0 |
| 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2.5 | 0 | 2.5 | 2.5 |
| 2 | 5 | 0 | 0 | 0 | 0 | 2.5 | 0 | 2.5 | 0 | 2.5 | 2.5 |
| 3 | 1 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 | 0 | 2.5 | 2.5 |
| 3 | 2 | 2.5 | 0 | 2.5 | 0 | 0 | 2.5 | 0 | 0 | 0 | 2.5 |
| 3 | 3 | 0 | 0 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 | 0 |
| 3 | 4 | 0 | 0 | 0 | 0 | 2.5 | 0 | 2.5 | 0 | 0 | 0 |
| 3 | 5 | 2.5 | 2.5 | 0 | 2.5 | 2.5 | 0 | 2.5 | 0 | 0 | 0 |

**Table 27.** Forb cover (%) in August 1995.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 0 | 0 | 0 | 2.5 | 2.5 |
| 1 | 2 | 2.5 | 15 | 15 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| 1 | 3 | 0 | 2.5 | 0 | 0 | 0 | 2.5 | 2.5 | 2.5 | 0 | 2.5 |
| 1 | 4 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| 1 | 5 | 15 | 15 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 2.5 | 2.5 | 2.5 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 |
| 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2.5 | 2.5 | 0 | 2.5 |
| 2 | 4 | 2.5 | 2.5 | 0 | 0 | 0 | 0 | 2.5 | 2.5 | 2.5 | 2.5 |
| 2 | 5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| 3 | 1 | 2.5 | 2.5 | 2.5 | 0 | 2.5 | 0 | 0 | 0 | 0 | 2.5 |
| 3 | 2 | 2.5 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 2.5 | 0 | 0 |
| 3 | 3 | 0 | 0 | 2.5 | 2.5 | 0 | 0 | 2.5 | 2.5 | 2.5 | 2.5 |
| 3 | 4 | 2.5 | 0 | 0 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| 3 | 5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |

**Table 28.** Nonseeded species cover (%) in August 1995.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 0 | 0 | 0 | 2.5 | 2.5 | 0 | 2.5 | 2.5 | 2.5 | 0 |
| 1 | 2 | 2.5 | 15 | 2.5 | 15 | 15 | 2.5 | 0 | 15 | 15 | 15 |
| 1 | 3 | 0 | 0 | 0 | 2.5 | 0 | 2.5 | 0 | 0 | 0 | 0 |
| 1 | 4 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 37.5 | 15 | 2.5 | 37.5 |
| 1 | 5 | 2.5 | 15 | 15 | 15 | 15 | 15 | 2.5 | 2.5 | 37.5 | 2.5 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 0 | 0 | 0 | 0 |
| 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.5 |
| 2 | 4 | 0 | 0 | 0 | 0 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| 2 | 5 | 15 | 37.5 | 15 | 2.5 | 2.5 | 2.5 | 2.5 | 15 | 2.5 | 2.5 |
| 3 | 1 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2 | 0 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 4 | 0 | 0 | 0 | 0 | 2.5 | 0 | 2.5 | 2.5 | 2.5 | 2.5 |
| 3 | 5 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 | 2.5 | 15 | 15 |

**Table 29.** Legume density in August 1995.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 1 | 2 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| 1 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 4 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 1 | 5 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 2 | 1 | 1 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 3 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 3 |
| 3 | 2 | 1 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 3 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 3 | 4 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 |
| 3 | 5 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |

**Table 30.** Forb density in August 1995.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 0 | 5 | 1 | 1 | 4 | 2 | 3 | 0 | 0 | 1 |
| 1 | 2 | 3 | 2 | 1 | 11 | 1 | 4 | 2 | 1 | 2 | 2 |
| 1 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 1 | 4 | 2 | 4 | 5 | 3 | 0 | 4 | 3 | 5 | 1 | 2 |
| 1 | 5 | 15 | 12 | 4 | 4 | 2 | 7 | 4 | 5 | 7 | 4 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 1 | 3 | 9 | 2 | 1 | 1 | 2 | 0 | 0 | 0 |
| 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 2 | 4 | 1 | 0 | 1 | 0 | 0 | 0 | 5 | 2 | 4 | 2 |
| 2 | 5 | 1 | 2 | 0 | 1 | 1 | 1 | 3 | 3 | 0 | 1 |
| 3 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 3 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 2 |
| 3 | 4 | 2 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 1 | 3 |
| 3 | 5 | 3 | 5 | 6 | 6 | 1 | 3 | 1 | 1 | 5 | 2 |

**Table 31.** Perennial grass density in August 1995.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 7 | 14 | 10 | 11 | 11 | 9 | 9 | 8 | 8 | 6 |
| 1 | 2 | 10 | 14 | 6 | 14 | 6 | 8 | 8 | 0 | 3 | 11 |
| 1 | 3 | 6 | 14 | 7 | 9 | 4 | 2 | 2 | 6 | 5 | 9 |
| 1 | 4 | 7 | 4 | 12 | 10 | 10 | 9 | 2 | 5 | 11 | 5 |
| 1 | 5 | 15 | 8 | 8 | 6 | 8 | 15 | 14 | 11 | 13 | 10 |
| 2 | 1 | 9 | 6 | 5 | 9 | 1 | 1 | 0 | 0 | 0 | 0 |
| 2 | 2 | 10 | 11 | 14 | 7 | 16 | 12 | 7 | 5 | 6 | 4 |
| 2 | 3 | 0 | 9 | 5 | 3 | 3 | 7 | 15 | 16 | 9 | 7 |
| 2 | 4 | 3 | 2 | 1 | 1 | 1 | 4 | 10 | 7 | 5 | 8 |
| 2 | 5 | 4 | 6 | 8 | 3 | 4 | 10 | 11 | 15 | 14 | 2 |
| 3 | 1 | 8 | 9 | 12 | 4 | 6 | 8 | 3 | 5 | 8 | 11 |
| 3 | 2 | 6 | 10 | 8 | 9 | 8 | 6 | 1 | 8 | 8 | 11 |
| 3 | 3 | 10 | 6 | 12 | 10 | 7 | 15 | 11 | 8 | 9 | 8 |
| 3 | 4 | 7 | 3 | 10 | 7 | 5 | 9 | 9 | 6 | 10 | 6 |
| 3 | 5 | 12 | 18 | 11 | 9 | 4 | 7 | 4 | 7 | 9 | 7 |

**Table 32.** Nonseeded species density in August 1995.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 2 | 1 | 1 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 1 |
| 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 4 | 3 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 1 | 5 | 0 | 0 | 2 | 1 | 2 | 0 | 1 | 0 | 1 | 1 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 2 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 2 | 5 | 2 | 5 | 1 | 3 | 1 | 1 | 1 | 2 | 1 | 1 |
| 3 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 3 | 5 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 2 | 1 | 0 |

**Table 33.** Perennial grass cover (%) in July 1996

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 15 | 0 | 2.5 | 2.5 | 37.5 | 2.5 | 2.5 | 15 | 0 | 2.5 |
| 1 | 2 | 85 | 62.5 | 85 | 37.5 | 62.5 | 62.5 | 62.5 | 62.5 | 62.5 | 85 |
| 1 | 3 | 15 | 2.5 | 2.5 | 15 | 15 | 37.5 | 15 | 15 | 37.5 | 37.5 |
| 1 | 4 | 15 | 15 | 2.5 | 2.5 | 15 | 15 | 37.5 | 37.5 | 2.5 | 15 |
| 1 | 5 | 2.5 | 15 | 15 | 15 | 15 | 2.5 | 37.5 | 37.5 | 2.5 | 62.5 |
| 2 | 1 | 2.5 | 2.5 | 15 | 37.5 | 0 | 2.5 | 0 | 0 | 2.5 | 2.5 |
| 2 | 2 | 62.5 | 85 | 37.5 | 62.5 | 85 | 97.5 | 85 | 62.5 | 62.5 | 85 |
| 2 | 3 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 15 | 37.5 | 15 | 15 | 15 |
| 2 | 4 | 15 | 15 | 2.5 | 15 | 37.5 | 2.5 | 2.5 | 2.5 | 2.5 | 15 |
| 2 | 5 | 15 | 15 | 15 | 37.5 | 2.5 | 2.5 | 15 | 15 | 15 | 2.5 |
| 3 | 1 | 2.5 | 2.5 | 2.5 | 15 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 15 |
| 3 | 2 | 37.5 | 37.5 | 85 | 37.5 | 62.5 | 85 | 97.5 | 85 | 97.5 | 85 |
| 3 | 3 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 15 | 2.5 | 2.5 | 2.5 |
| 3 | 4 | 2.5 | 15 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 15 | 2.5 | 2.5 |
| 3 | 5 | 15 | 15 | 15 | 15 | 15 | 15 | 37.5 | 2.5 | 15 | 37.5 |

**Table 34.** Forb cover (%) in July 1996.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 |
| 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 3 | 2.5 | 0 | 0 | 0 | 2.5 | 0 | 2.5 | 15 | 15 | 2.5 |
| 1 | 4 | 15 | 2.5 | 15 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 15 |
| 1 | 5 | 2.5 | 0 | 2.5 | 15 | 2.5 | 2.5 | 2.5 | 0 | 15 | 2.5 |
| 2 | 1 | 0 | 0 | 0 | 2.5 | 0 | 0 | 2.5 | 0 | 2.5 | 2.5 |
| 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 3 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 0 | 0 | 0 |
| 2 | 4 | 0 | 0 | 0 | 0 | 2.5 | 0 | 2.5 | 2.5 | 2.5 | 2.5 |
| 2 | 5 | 2.5 | 2.5 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0 | 2.5 | 2.5 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 2.5 |
| 3 | 4 | 0 | 0 | 0 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 2.5 |
| 3 | 5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 2.5 | 2.5 |

**Table 35.** Legume cover (%) in July 1996.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 3 | 2.5 | 0 | 0 | 15 | 0 | 0 | 15 | 0 | 0 | 15 |
| 1 | 4 | 15 | 0 | 0 | 15 | 0 | 2.5 | 0 | 0 | 15 | 2.5 |
| 1 | 5 | 0 | 15 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 0 | 2.5 | 2.5 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2.5 | 0 | 0 | 0 |
| 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 3 | 0 | 2.5 | 0 | 15 | 15 | 0 | 0 | 0 | 0 | 0 |
| 2 | 4 | 15 | 0 | 0 | 0 | 2.5 | 15 | 15 | 2.5 | 2.5 | 0 |
| 2 | 5 | 0 | 2.5 | 0 | 15 | 37.5 | 2.5 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 2.5 | 0 | 0 | 0 | 0 | 2.5 | 0 | 0 |
| 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 2.5 | 0 | 15 | 2.5 | 0 | 2.5 | 0 | 2.5 | 15 | 0 |
| 3 | 4 | 0 | 0 | 0 | 0 | 0 | 15 | 15 | 15 | 2.5 | 2.5 |
| 3 | 5 | 0 | 15 | 2.5 | 0 | 2.5 | 15 | 0 | 0 | 0 | 0 |

**Table 36.** Nonseeded species cover (%) in July 1996.

| | | Frame | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1 | 0 | 0 | 0 | 2.5 | 2.5 | 2.5 | 0 | 0 | 0 | 0 |
| 1 | 2 | 2.5 | 0 | 2.5 | 15 | 15 | 0 | 0 | 2.5 | 15 | 15 |
| 1 | 3 | 37.5 | 2.5 | 15 | 15 | 15 | 15 | 15 | 15 | 2.5 | 2.5 |
| 1 | 4 | 15 | 15 | 2.5 | 2.5 | 15 | 15 | 15 | 15 | 2.5 | 15 |
| 1 | 5 | 37.5 | 37.5 | 37.5 | 15 | 37.5 | 85 | 37.5 | 37.5 | 15 | 2.5 |
| 2 | 1 | 0 | 0 | 2.5 | 2.5 | 0 | 0 | 0 | 0 | 2.5 | 2.5 |
| 2 | 2 | 0 | 0 | 0 | 0 | 15 | 0 | 15 | 2.5 | 0 | 15 |
| 2 | 3 | 2.5 | 15 | 37.5 | 2.5 | 2.5 | 2.5 | 2.5 | 15 | 2.5 | 15 |
| 2 | 4 | 37.5 | 37.5 | 62.5 | 15 | 37.5 | 37.5 | 37.5 | 37.5 | 62.5 | 62.5 |
| 2 | 5 | 97.5 | 85 | 37.5 | 2.5 | 15 | 2.6 | 15 | 62.5 | 37.5 | 62.5 |
| 3 | 1 | 0 | 0 | 2.5 | 2.5 | 2.5 | 0 | 0 | 2.5 | 0 | 0 |
| 3 | 2 | 2.5 | 15 | 2.5 | 0 | 2.5 | 15 | 2.5 | 15 | 0 | 15 |
| 3 | 3 | 2.5 | 2.5 | 0 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 0 | 2.5 |
| 3 | 4 | 2.5 | 15 | 2.5 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 15 |
| 3 | 5 | 15 | 15 | 37.5 | 62.5 | 2.5 | 15 | 2.5 | 37.5 | 85 | 15 |

**Table 37.** *Agropyron spicatum* production (grams/25cm$^2$) in July 1996

| | | Frame | | | | | |
|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1 | 0 | 0.61 | 0 | 0 | 0 | 0 |
| 1 | 2 | 5.93 | 0 | 2.49 | 1.66 | 0 | 3.33 |
| 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 5 | 0 | 0 | 0 | 0 | 5.24 | 3.08 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 1.97 | 0 | 0 | 0 | 13.32 | 0 |
| 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2 | 1.62 | 0 | 0 | 9.26 | 0 | 5.10 |
| 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 38.** *Agropyron smithii* production (grams/25cm$^2$) in July 1996

| | | Frame | | | | | |
|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1 | 0.52 | 6.58 | 5.86 | 1.79 | 1.38 | 0.27 |
| 1 | 2 | 24.67 | 13.06 | 44.07 | 0 | 0 | 8.71 |
| 1 | 3 | 0 | 1.81 | 0 | 0 | 0 | 0 |
| 1 | 4 | 0 | 0 | 1.86 | 0 | 0 | 0 |
| 1 | 5 | 24.70 | 0 | 4.15 | 1.16 | 2.56 | 4.00 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 124.65 | 7.15 | 0 | 7.94 | 4.49 | 53.86 |
| 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 5 | 0 | 2.54 | 0 | 0 | 0 | 1.73 |
| 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2 | 0 | 0 | 0 | 1.04 | 0 | 66.62 |
| 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 5 | 0 | 0 | 15.38 | 0 | 0 | 0 |

**Table 39.** *Agropyron trachycaulum* production (grams/25cm$^2$) in July 1996

| | | Frame | | | | | |
|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 2 | 42.84 | 0 | 0 | 12.77 | 73.12 | 48.39 |
| 1 | 3 | 2.95 | 0 | 6.42 | 5.20 | 0 | 6.46 |
| 1 | 4 | 6.54 | 1.35 | 0 | 0.65 | 9.31 | 1.37 |
| 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1.45 | 0 | 1.07 | 0 | 0.84 | 1.69 |
| 2 | 2 | 0 | 21.06 | 41.08 | 68.84 | 31.22 | 0 |
| 2 | 3 | 0 | 0 | 1.60 | 3.31 | 8.67 | 15.11 |
| 2 | 4 | 33.10 | 0 | 8.36 | 5.33 | 4.17 | 6.86 |
| 2 | 5 | 7.14 | 10.96 | 7.26 | 3.37 | 1.76 | 4.41 |
| 3 | 1 | 0.99 | 0 | 16.06 | 0 | 1.22 | 3.05 |
| 3 | 2 | 15.63 | 24.11 | 40.61 | 81.46 | 70.21 | 0 |
| 3 | 3 | 0 | 0 | 1.23 | 16.07 | 0 | 6.45 |
| 3 | 4 | 0 | 0 | 3.49 | 3.36 | 2.39 | 2.72 |
| 3 | 5 | 14.50 | 11.07 | 0 | 14.26 | 14.13 | 17.50 |

**Table 40.** Nonseeded grass production (grams/25cm$^2$) in July 1996

| | | Frame | | | | | |
|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1 | 0 | 1.73 | 1.40 | 1.04 | 0 | 0 |
| 1 | 2 | 12.12 | 14.23 | 2.82 | 18.41 | 4.44 | 0 |
| 1 | 3 | 3.13 | 1.20 | 3.72 | 0 | 14.32 | 0 |
| 1 | 4 | 1.95 | 0 | 0 | 1.02 | 0 | 0 |
| 1 | 5 | 1.66 | 10.38 | 1.06 | 3.81 | 3.62 | 8.41 |
| 2 | 1 | 0 | 0.97 | 0 | 0 | 0 | 3.54 |
| 2 | 2 | 0 | 0 | 9.00 | 0 | 0 | 0 |
| 2 | 3 | 0.48 | 0. | 0 | 1.95 | 4.28 | 0 |
| 2 | 4 | 0 | 20.23 | 9.81 | 0 | 3.37 | 2.07 |
| 2 | 5 | 5.65 | 2.24 | 0 | 1.48 | 3.04 | 7.00 |
| 3 | 1 | 0 | 0.58 | 2.45 | 1.20 | 0 | 0 |
| 3 | 2 | 3.59 | 0 | 33.86 | 1.52 | 3.60 | 0 |
| 3 | 3 | 0.33 | 0.29 | 0 | 0 | 0.96 | 0 |
| 3 | 4 | 13.60 | 1.47 | 0 | 0 | 2.72 | 2.60 |
| 3 | 5 | 0 | 3.74 | 0 | 0 | 9.37 | 7.46 |

**Table 41.** Nonseeded forb production (grams/25cm$^2$) in July 1996

| | | Frame | | | | | |
|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 2 | 0 | 0 | 0 | 0 | 5.17 | 0 |
| 1 | 3 | 1.40 | 0.88 | 0 | 0 | 2.36 | 0 |
| 1 | 4 | 3.90 | 0.44 | 0.07 | 1.15 | 0.05 | 0 |
| 1 | 5 | 1.33 | 11.15 | 0 | 4.19 | 10.96 | 1.10 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 3 | 0 | 0.80 | 0 | 0 | 0.29 | 0 |
| 2 | 4 | 5.47 | 1.67 | 0 | 2.03 | 5.27 | 4.91 |
| 2 | 5 | 24.22 | 12.02 | 4.06 | 1.33 | 1.53 | 0 |
| 3 | 1 | 0.17 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0.22 | 0 | 0 | 2.40 | 0 | 0.84 |
| 3 | 4 | 1.44 | 1.28 | 0 | 0 | 1.02 | 0 |
| 3 | 5 | 1.73 | 3.95 | 0 | 0.86 | 0 | 9.47 |

**Table 42.** *Elymus cinereus* production (grams/$25cm^2$) in July 1996

| | | Frame | | | | | |
|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 2 | 0 | 8.40 | 0 | 0 | 0 | 0 |
| 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 1.98 | 0 | 0 | 2.20 | 0 | 2.25 |
| 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 43.** *Agropyron riparium* production (grams/25cm$^2$) in July 1996

| | | Frame | | | | | |
|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 44.** *Linum perenne* production (grams/25cm$^2$) in July 1996

| | | Frame | | | | | |
|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 3 | 0.84 | 0 | 0 | 1.31 | 0 | 0 |
| 1 | 4 | 0.80 | 0 | 0 | 0.89 | 0 | 0.28 |
| 1 | 5 | 0 | 0 | 1.15 | 0 | 0.52 | 1.32 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 3 | 0 | 0 | 1.20 | 0 | 0 | 0 |
| 2 | 4 | 0 | 0 | 4.26 | 0 | 0 | 0 |
| 2 | 5 | 0 | 0 | 1.65 | 3.67 | 0 | 1.88 |
| 3 | 1 | 0 | 0 | 0 | 0 | 0.07 | 0 |
| 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0 | 1.10 | 0 | 0 | 1.00 | 0 |
| 3 | 4 | 0 | 0 | 0 | 2.17 | 1.38 | 0.85 |
| 3 | 5 | 0.97 | 0.41 | 0.71 | 0 | 0 | 1.44 |

**Table 45.** *Onobrychis viciaefolia* production (grams/25cm$^2$) in July 1996

| | | Frame | | | | | |
|---|---|---|---|---|---|---|---|
| Rep | Plot | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 3 | 0.25 | 0 | 0.04 | 0.20 | 0 | 0.74 |
| 1 | 4 | 0.96 | 0.29 | 0.19 | 0 | 0 | 0.18 |
| 1 | 5 | 0 | 0 | 0.74 | 0.54 | 0 | 0.76 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 3 | 0.68 | 0.08 | 0.13 | 0 | 0 | 0 |
| 2 | 4 | 0 | 0 | 0 | 0.61 | 0 | 0.50 |
| 2 | 5 | 0.47 | 0 | 0 | 0.46 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0 | 0 | 0.09 | 0 | 0 | 0 |
| 3 | 4 | 0 | 0 | 0.85 | 0 | 0 | 0.89 |
| 3 | 5 | 0.64 | 0.31 | 0 | 0.17 | 0.93 | 0 |

# APPENDIX C

# ANOVA TABLES

Table 46. Analysis of variance for pretreatment tailings total arsenic, total cadmium, total lead, total mangenese (p = 0.05).

**Total arsenic**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.25 | 0.12 | 2.70 | 0.18 |
| Treatment | 2 | 0.10 | 0.05 | 1.04 | 0.43 |
| Error | 4 | 0.18 | 0.05 | | |

**Total cadmium**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.27 | 0.13 | 1.45 | 0.34 |
| Treatment | 2 | 0.11 | 0.05 | 0.59 | 0.60 |
| Error | 4 | 0.37 | 0.09 | | |

**Total lead**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 9.56 | 4.78 | 0.54 | 0.62 |
| Treatment | 2 | 5.56 | 2.78 | 0.32 | 0.75 |
| Error | 4 | 35.11 | 8.78 | | |

**Total mangenese**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 1248.67 | 624.33 | 2.73 | 0.18 |
| Treatment | 2 | 224.00 | 112.00 | 0.49 | 0.65 |
| Error | 4 | 915.33 | 228.83 | | |

**Table 47.** Analysis of variance for pretreatment tailings sand, silt, clay, and EC (p = 0.05).

**Sand**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 88.67 | 44.33 | 1.66 | 0.30 |
| Treatment | 2 | 338.67 | 169.33 | 6.35 | 0.057 |
| Error | 4 | 106.67 | 26.67 | | |

**Silt**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 8.22 | 4.11 | 0.34 | 0.73 |
| Treatment | 2 | 13.56 | 6.78 | 0.57 | 0.61 |
| Error | 4 | 47.78 | 11.94 | | |

**Clay**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 44.22 | 22.11 | 2.08 | 0.24 |
| Treatment | 2 | 242.89 | 121.44 | 11.45 | 0.02 |
| Error | 4 | 42.44 | 10.61 | | |

**EC**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.02 | 0.01 | 0.15 | 0.87 |
| Treatment | 2 | 0.03 | 0.01 | 0.24 | 0.79 |
| Error | 4 | 0.22 | 0.06 | | |

**Table 48.** Analysis of variance for pretreatment tailings total zinc, total copper, total iron, total aluminum (p = 0.05).

**Total zinc**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 3.15 | 1.57 | 8.24 | 0.04 |
| Treatment | 2 | 0.84 | 0.42 | 2.20 | 0.23 |
| Error | 4 | 0.76 | 0.19 | | |

**Total copper**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 2.11 | 1.05 | 1.08 | 0.42 |
| Treatment | 2 | 5.91 | 2.95 | 3.02 | 0.16 |
| Error | 4 | 3.91 | 0.98 | | |

**Total iron**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.07 | 0.03 | 1.31 | 0.36 |
| Treatment | 2 | 0.03 | 0.02 | 0.62 | 0.58 |
| Error | 4 | 0.11 | 0.03 | | |

**Total aluminum**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.06 | 0.03 | 1.49 | 0.33 |
| Treatment | 2 | 0.01 | 0.01 | 0.36 | 0.72 |
| Error | 4 | 0.08 | 0.02 | | |

**Table 49.** Analysis of variance for pretreatment tailings potassium, nitrogen, phosphorous, and pH (p = 0.05).

**Potassium**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 355.56 | 177.78 | 13.56 | 0.017 |
| Treatment | 2 | 24.89 | 12.44 | 0.95 | 0.46 |
| Error | 4 | 52.44 | 13.11 | | |

**Nitrogen**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 1.32 | 0.66 | 0.75 | 0.53 |
| Treatment | 2 | 4.22 | 2.11 | 2.41 | 0.21 |
| Error | 4 | 3.50 | 0.87 | | |

**Phosphorous**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.01 | 0.00 | 1.00 | 0.44 |
| Treatment | 2 | 0.01 | 0.00 | 1.00 | 0.44 |
| Error | 4 | 0.01 | 0.00 | | |

**pH**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.01 | 0.00 | 4.00 | 0.11 |
| Treatment | 2 | 0.00 | 0.00 | 1.00 | 0.44 |
| Error | 4 | 0.00 | 0.00 | | |

**Table 50.** Analysis of variance for pretreatment tailings paste magnesium, paste sodium, paste calcium, and paste copper (p = 0.05).

**Paste magnesium**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 156.22 | 78.11 | 0.18 | 0.84 |
| Treatment | 2 | 681.56 | 340.78 | 0.78 | 0.52 |
| Error | 4 | 1752.44 | 438.11 | | |

**Paste sodium**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 22.89 | 11.44 | 0.16 | 0.85 |
| Treatment | 2 | 69.56 | 34.78 | 0.50 | 0.64 |
| Error | 4 | 277.78 | 69.44 | | |

**Paste calcium**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 329.56 | 164.78 | 0.21 | 0.82 |
| Treatment | 2 | 90.89 | 45.44 | 0.06 | 0.94 |
| Error | 4 | 3084.44 | 771.11 | | |

**Paste copper**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.00 | 0.00 | 1.00 | 0.44 |
| Treatment | 2 | 0.00 | 0.00 | 67.00 | 0.00 |
| Error | 4 | 0.00 | 0.00 | | |

**Table 51.** Analysis of variance for pretreatment tailings paste arsenic, paste iron, paste cadmium and paste lead ($p = 0.05$).

**Paste arsenic**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.00 | 0.00 | 0.00 | 1.00 |
| Treatment | 2 | 0.00 | 0.00 | 0.00 | 1.00 |
| Error | 4 | 0.00 | 0.00 | | |

**Paste iron**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.00 | 0.00 | 0.00 | 1.00 |
| Treatment | 2 | 0.00 | 0.00 | 0.00 | 1.00 |
| Error | 4 | 0.00 | 0.00 | | |

**Paste cadmium**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 200000.00 | 10000.00 | 0.00 | 0.00 |
| Treatment | 2 | 0.00 | 0.00 | 0.00 | 1.00 |
| Error | 4 | 0.00 | 0.00 | | |

**Paste lead**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.00 | 0.00 | 0.00 | 1.00 |
| Treatment | 2 | 0.00 | 0.00 | 0.00 | 1.00 |
| Error | 4 | 0.00 | 0.00 | | |

**Table 52.** Analysis of variance for pretreatment tailings paste mangenese, paste sulfate, paste zinc and saturation % (p = 0.05).

**Paste mangenese**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.00 | 0.00 | 3.06 | 0.16 |
| Treatment | 2 | 0.00 | 0.00 | 1.82 | 0.27 |

**Paste sulfate**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 4260.22 | 2130.11 | 0.08 | 0.92 |
| Treatment | 2 | 30128.22 | 15064.11 | 0.58 | 0.60 |
| Error | 4 | 103873.10 | 25968.28 | | |

**Paste zinc**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.05 | 0.02 | 0.38 | 0.71 |
| Treatment | 2 | 0.01 | 0.01 | 0.12 | 0.89 |
| Error | 4 | 0.25 | 0.06 | | |

**SAR**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.01 | 0.00 | 0.20 | 0.83 |
| Treatment | 2 | 0.01 | 0.00 | 0.20 | 0.83 |
| Error | 4 | 0.07 | 0.02 | | |

**Saturation %**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 84.98 | 42.49 | 2.23 | 0.22 |
| Treatment | 2 | 510.85 | 255.42 | 13.40 | 0.02 |
| Error | 4 | 76.25 | 19.06 | | |

**Table 53.** Analysis of variance for production (1996) of *Agropyron spicatum, Agropyron smithii, Agropyron trachycaulum, Linum perenne* and *Onobrychis viciaefolia* on treated plots (p = 0.05).

***Agropyron spicatum***

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.17 | 0.09 | 0.56 | 0.60 |
| Treatment | 4 | 13.82 | 3.46 | 22.66 | 0.00 |
| Error | 8 | 1.22 | 0.15 | | |

***Agropyron smithii***

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 1.75 | 0.88 | 1.42 | 0.30 |
| Treatment | 4 | 36.95 | 9.24 | 14.94 | 0.00 |
| Error | 8 | 4.95 | 0.62 | | |

***Agropyron trachycaulum***

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 56.90 | 28.40 | 1.74 | 0.24 |
| Treatment | 4 | 1865.00 | 466.30 | 28.47 | 0.00 |
| Error | 8 | 131.00 | 16.40 | | |

***Linum perenne***

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.01 | 0.01 | 1.15 | 0.37 |
| Treatment | 4 | 0.21 | 0.05 | 11.85 | 0.00 |
| Error | 8 | 0.04 | 0.00 | | |

***Onobrychis viciaefolia***

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.09 | 0.04 | 1.04 | 0.40 |
| Treatment | 4 | 1.41 | 0.35 | 8.64 | 0.01 |
| Error | 8 | 0.33 | 0.04 | | |

**Table 54.** Analysis of variance for density (1995) of forb, perennial grasses, legume and nonseeded species on treated plots (p = 0.05).

**Forb**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 10.71 | 5.35 | 4.32 | 0.05 |
| Treatment | 4 | 20.36 | 5.09 | 4.10 | 0.04 |
| Error | 8 | 9.92 | 1.24 | | |

**Perennial grasses**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 12.60 | 6.32 | 1.94 | 0.21 |
| Treatment | 4 | 16.10 | 4.04 | 1.24 | 0.37 |
| Error | 8 | 26.00 | 3.25 | | |

**Legume**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.28 | 0.14 | 8.53 | 0.01 |
| Treatment | 4 | 0.30 | 0.08 | 4.61 | 0.03 |
| Error | 8 | 0.13 | 0.02 | | |

**Nonseeded species**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.18 | 0.09 | 0.68 | 0.54 |
| Treatment | 4 | 1.88 | 0.47 | 3.59 | 0.06 |
| Error | 8 | 1.05 | 0.13 | | |

**Table 55.** Analysis of variance for cover (1995) of forb, perennial grasses, legume and nonseeded species on treated plots (p = 0.05).

**Forb**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 9.70 | 4.85 | 5.85 | 0.03 |
| Treatment | 4 | 11.44 | 2.86 | 3.45 | 0.06 |
| Error | 8 | 6.63 | 0.83 | | |

**Perennial grasses**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 138.70 | 69.30 | 0.55 | 0.60 |
| Treatment | 4 | 236.60 | 59.20 | 0.47 | 0.76 |
| Error | 8 | 1013.50 | 126.70 | | |

**Legume**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.91 | 0.45 | 3.21 | 0.09 |
| Treatment | 4 | 0.69 | 0.17 | 1.22 | 0:37 |
| Error | 8 | 1.13 | 0.14 | | |

**Nonseeded species**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 93.30 | 46.65 | 5.81 | 0.03 |
| Treatment | 4 | 136.30 | 34.07 | 4.24 | 0.04 |
| Error | 8 | 64.30 | 8.03 | | |

**Table 56.** Analysis of variance for cover (1996) of forb, perennial grasses, legume and nonseeded species on treated plots ($p = 0.05$).

**Forb**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 12.70 | 6.34 | 3.84 | 0.07 |
| Treatment | 4 | 22.90 | 5.72 | 3.47 | 0.06 |
| Error | 8 | 13.20 | 1.65 | | |

**Perennial grasses**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 66.60 | 33.30 | 1.70 | 0.24 |
| Treatment | 4 | 8481.80 | 2120.40 | 108.32 | 0.00 |
| Error | 8 | 156.60 | 19.60 | | |

**Legume**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 0.08 | 0.04 | 0.63 | 0.56 |
| Treatment | 4 | 13.14 | 3.28 | 52.00 | 0.00 |
| Error | 8 | 0.50 | 0.06 | | |

**Nonseeded species**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 325.20 | 162.60 | 1.98 | 0.20 |
| Treatment | 4 | 2202.80 | 550.70 | 6.70 | 0.01 |
| Error | 8 | 657.10 | 82.10 | | |

**Table 57.** Analysis of variance for production of total seeded grasses, nonseeded grasses, nonseeded forbs and total vegetation on treated plots (p = 0.05).

**Total seeded grasses**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 38.30 | 19.10 | 0.94 | 0.43 |
| Treatment | 4 | 5975.20 | 1493.80 | 73.63 | 0.00 |
| Error | 8 | 162.30 | 20.30 | | |

**Nonseeded grasses**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 4.49 | 2.25 | 1.72 | 0.24 |
| Treatment | 4 | 48.36 | 12.09 | 9.24 | 0.00 |
| Error | 8 | 10.47 | 1.31 | | |

**Nonseeded forbs**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 3.52 | 1.76 | 0.30 | 0.75 |
| Treatment | 4 | 45.68 | 11.42 | 1.92 | 0.20 |
| Error | 8 | 47.57 | 5.95 | | |

**Total vegetation**

| Source | df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Block | 2 | 33.40 | 16.70 | 0.99 | 0.41 |
| Treatment | 4 | 6643.60 | 1660.90 | 98.60 | 0.00 |
| Error | 8 | 134.80 | 16.80 | | |

# APPENDIX D

# PRECIPITATION DATA

**Table 58.** Monthly precipitation (cm) for Dillon, Montana (Dillon WMCE) for 1995.

| Month | Precipitation | Deviation |
|---|---|---|
| January | 2.6 | +1.8 |
| February | 0.3 | -0.3 |
| March | 2.3 | +0.8 |
| April | 7.9 | +4.8 |
| May | 10.9 | +5.6 |
| June | 10.2 | +4.8 |
| July | 4.3 | +1.3 |
| August | 2.5 | -0.8 |
| September | 5.3 | +2.3 |
| October | 1.5 | -0.3 |
| November | 0.3 | -1.0 |
| December | 1.0 | 0.0 |

**Table 59.** Monthly precipitation (cm) for Dillon, Montana (Dillon WMCE) for the first six months of 1996.

| Month | Precipitation | Deviation |
|---|---|---|
| January | 0.5 | -0.3 |
| February | 1.8 | +1.3 |
| March | 2.8 | +1.3 |
| April | 2.0 | -1.0 |
| May | 7.3 | +2.0 |
| June | 1.4 | -3.8 |