Evaluation of amendments for a topsoil substitute at the Stillwater Mine

by Heidi Jill Kaiser

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

Abstract:
Topsoil is an invaluable resource for use in reclamation of disturbed lands. It is often in short supply, particularly when dealing with disturbances related to underground mining. The paucity of topsoil available at the Stillwater Mine, a platinum group metals mine in south central Montana, prompted a study evaluating an alternative for native topsoil materials at the site.

The subject of this study is the crushed rock or cuttings produced by the Tunnel Boring Machine which was utilized during the underground mining process at the Stillwater Mine. This crushed rock is considered waste and is disposed of through ongoing construction of the tailings impoundment, portal sites, and access roads. The cuttings contain no phytotoxic materials and are barren of essential plant available nutrients. They are comprised of about 50 percent loamy sand (<2 mm particle diameter), 15 percent small rock fragments (2 mm to 5 cm) and 35 percent coarse materials (>5 cm) Revegetation trials on the cuttings were initiated in the fall of 1988 with the construction of test plots. Five mulch treatments were applied to the cuttings in combination with organic and inorganic fertilizer applications. The plots were seeded with drought tolerant species adapted to the climate of the mine site. Plant growth was evaluated by measuring percent canopy cover and biomass production during the first and sixth growing seasons.

Results of the revegetation trials indicated that there were no major significant differences in the response of plant cover or production among the different mulch treatments in 1989 or 1994. There were, however, significant differences among the plant responses to the fertilizer subtreatments in both years. Plant production was enhanced by the addition of phosphorus to the Biosol in 1989 and by both the mineral fertilizer and Biosol + P in 1994. We may infer that the addition of extra phosphorus as a mineral fertilizer or as an amendment to Biosol is necessary to maximize perennial grass and forb production in the materials used as a coversoil substitute at the Stillwater Mine.

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

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Date *November 30, 1995*

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TABLE OF CONTENTS

TABLE OF CONTENTS. Continued

LIST OF TABLES

LIST OF TABLES. Continued

LIST OF FIGURES

ABSTRACT

Topsoil is an invaluable resource for use in reclamation of disturbed lands. It is often in short supply, particularly when dealing with disturbances related to underground mining. The paucity of topsoil available at the Stillwater Mine, a platinum group metals mine in south central Montana, prompted a study evaluating an alternative for native topsoil materials at the site.

The subject of this study is the crushed rock or cuttings produced by the Tunnel Boring Machine which was utilized during the underground mining process at the Stillwater Mine. This crushed rock is considered waste and is disposed of through ongoing construction of the tailings impoundment, portal sites, and access roads. The cuttings contain no phytotoxic materials and are barren of essential plant available nutrients. They are comprised of about 50 percent loamy sand (<2 mm particle diameter), 15 percent small rock fragments (2 mm to 5 cm) and 35 percent coarse materials (>5 cm)

Revegetation trials on the cuttings were initiated in the fall of 1988 with the construction of test plots. Five mulch treatments were applied to the cuttings in combination with organic and inorganic fertilizer applications. The plots were seeded with drought tolerant species adapted to the climate of the mine site. Plant growth was evaluated by measuring percent canopy cover and biomass production during the first and sixth growing seasons.

Results of the revegetation trials indicated that there were no major significant differences in the response of plant cover or production among the different mulch treatments in 1989 or 1994. There were, however, significant differences among the plant responses to the fertilizer subtreatments in both years. Plant production was enhanced by the addition of phosphorus to the Biosol in 1989 and by both the mineral fertilizer and Biosol + P in 1994. We may infer that the addition of extra phosphorus as a mineral fertilizer or as an amendment to Biosol is necessary to maximize perennial grass and forb production in the materials used as a coversoil substitute at the Stillwater Mine.

INTRODUCTION

Topsoil is an invaluable resource for use in reclamation of disturbed lands. It is often in short supply, particularly at disturbances related to underground mining. The purpose of this study was to enhance reclamation efforts at the Stillwater Mine by amending waste material to make it suitable for use as a coversoil during current and post mining reclamation activities.

During 1988 the Stillwater Mine employed a tunnel boring machine (TBM) to drive access adits to the ore zone. The grinding action of the rotating TBM cutter head created a greater portion of fine material in the cuttings than was generated during the conventional "drill and blast" method of advancing these adits. The rock encountered during the advance of the access adits is primarily an unweathered quartz monzanite. This crushed rock is essentially devoid of plant available nutrients, organic matter, and phytotoxic elements but it does have a greater water holding capacity than conventional waste rock because of the greater amount of fines in the TBM cuttings.

Reclamation of surface disturbances at the Stillwater Mine is concurrent with mining activities where it is possible. Revegetation is carried out to minimize erosion, decrease the visual impact of mine related disturbances, and provide forage for wildlife. For example, portal pads at adit entrances are constructed of light colored waste rock which creates a barren slope below the portal. Mining permits require that these slopes have minimal visual impact. In addition, access roads to portals are often constructed by cut and fill operations.

These roads must also blend visually with the surroundings. Topsoil or coversoil (if it exists) is removed before new construction and redistributed in the appropriate areas or stockpiled for final reclamation. Unfortunately, topsoil frequently is lacking or is of poor quality where these disturbances are located.

In an attempt to alleviate the problem of the topsoil deficit, substitutes for coversoil were examined at the Stillwater Mine. One alternative was the use of crushed rock produced by the TBM. These geologic materials do not contain plant available nutrients or organic matter. The elements necessary for vegetative establishment must be added to the mining waste to correct the deficiencies of these essential soil components. The objective of this study was to develop an alternative for topsoil by determining optimum fertilizer and mulch treatment(s) needed to sustain vegetative growth on TBM cuttings.

LITERATURE REVIEW

Most hard rock mining disturbances are found in or near alpine environments. They have not received the intensive review and research associated with coal mining activities. An important factor when dealing with high-elevation disturbances is the poor quality and insufficient quantity of topsoil generally found in this environment (Brown et al. 1978). These factors and effects of disturbing existing topsoil have led to research emphasizing organic enrichment of waste rock and other available soil materials as substitutes for surface soil coverings. The research carried out in these environments has contributed to a basic understanding of reclamation problems regarding plant species selection, soil fertility, and soil texture in these settings.

For example, reclamation of mining disturbances on the Beartooth Plateau, the location of several precious metals mines, has been studied by many scientists since the 1970's (Brown et al. 1976, 1978; Chambers et al. 1984; Guillaume 1984). Brown, Chambers and others found that organic matter incorporated into the surface of alpine soils together with fertilizer greatly enhances plant establishment. Guillaume's study supports these ideas and presents the finding that native species are better suited to alpine sites due to their adaptation to low growing temperatures and short growing seasons.

Other research at hardrock mine reclamation projects includes studies conducted at the Berkeley Pit in Butte, Montana, where Parady (1981) and Lawson (1984) used alluvial materials as coversoil to assist the revegetation of acidic waste dumps. The alluvial materials they used created soil crusts which were alleviated with the addition of organic matter. At the Zortman and Landusky Mines in north-central Montana, Spry (1986) concluded that low water availability was the main factor limiting revegetation trials on waste rock dumps and tailings. These trials did not involve the use of any topsoil cover on waste rock. The use of composted municiple waste was the subject of a revegetation study at the Basin Creek Mine carried out by Vodehnal (1993). This site straddles the continental divide near Helena, Montana. Vodehnal found that the composted waste enhanced seedling germination and plant establishment.

Topsoil vs Coversoil

Topsoil is defined as the surface soil which generally has a greater organic matter content than the deeper subsurface soil. It provides a good rooting medium, reduces runoff, improves infiltration, encourages faster reestablishment of nutrient cycles and increases species diversity of the vegetation cover (Schuman and Power 1981). Topsoil can be viewed as an amendment which accelerates the reclamation process. Microorganisms present in topsoil facilitate organic matter decomposition and are very important in renovating soil structure and cycling macronutrients. One of the greatest assets of topsoil is its texture (particle size distribution) which is important to soil/plant water relationships. Soil texture affects several critical factors of revegetation of disturbed sites (Sabey et al. 1987). These factors include moisture, temperature, aeration, root penetration, chemical activity and erosion.

Adequate revegetation requires a suitable growth medium, preferably and ideally topsoil, but this growth medium may be a material which does not meet all of the criteria associated with the definition of topsoil. Coversoil is a more appropriate term for those materials which may be salvaged from any soil horizon other than the A Horizon. Coversoil must be nontoxic and have a texture that will hold water for plant growth. If coversoil or other growth media satisfy these requirements, the nutrient and organic constituents can be provided by amendment with organic matter and fertilizer (Brown 1984a). Daniels and Amos (1984) reviewed the use of topsoil substitutes for reclamation in the southern Appalachian coal fields. They found that once rocky spoils (topsoil substitutes) are revegetated, the morphological, physical, chemical and mineralogical properties of the cover soil change quickly as the material weathers into mine soil.

Soil Texture

A growth medium available at the Stillwater Mine is TBM cuttings. This material is approximately 50 percent loamy sand with a percentage of small rock fragments created by the action of the TBM. While rock fragments (>2 mm) are not always considered desirable in topsoil materials they do have positive effects on the quality of soils in terms of reclamation potential. Some of these positive attributes include reduced susceptibility to erosion and compaction (Munn et al. 1987). Rock fragments also increase the macro porosity of soils which enhances water infiltration into the soils (Edwards et al. 1984). Water will penetrate to a greater depth in rocky soils compared with nonrocky soils of similar texture (Birkland 1984).

The fine or soil fraction (<2 mm) of the TBM cuttings is comprised of sand (0.05 to 2 mm), silt (0.002 to 0.05 mm) and clay (<0.002 mm) particles. The relative proportion of these particles in soil directly affects water infiltration, soil aeration, cation exchange capacity and erodibility (Munshower 1994). Coarse or sandy soils allow water to pass through the soil without retaining enough water for plant use. Fine soil particles such as clay, reduce permeability and retard water movement from the surface down into the soil. Clay soils retain water once the water enters the soil profile. Sometimes the water is held to tightly to be absorbed by plants. Silt loams or silts hold large quantities of water for plant growth even though much of this water is unavailable to plants (Lyle 1987). A soil with an intermediate texture, that is, a soil with enough sand to allow for aeration and looseness to permit plant root growth and development and enough clay for adequate nutrient and water-holding capacity would be ideal for reclamation.

Fertility

The two most limiting plant growth nutrients on mine soils in the western United States are nitrogen and phosphorous (Bauer et al. 1978). Fertilizer applications were also found to be absolutely essential to the successful and rapid establishment of plant cover on alpine disturbances (Brown 1984b). Nitrogen can be the most difficult nutrient to control because it remains in the soil for only short periods of time. Soil nitrogen is lost through plant uptake, rainwater leaching, use by microorganisms, and volatilization. A single application of fertilizer nitrogen for vegetation establishment may be inadequate to sustain the vegetation because nitrogen fertilizers may be depleted within a few weeks after application. Lyle (1987) recommends application of half of the nitrogen fertilizer before seeding and the other half 30 or 45 days following seeding. The need to re-apply nitrogen fertilizer during a single growing season may be eliminated by applying a slow release type of fertilizer. The long term nitrogen needs of vegetation (many years) may be met by planting nitrogen fixing plant species. Legumes add significant levels of nitrogen to geologic materials through nitrogen fixation. It is estimated that sweet clover can fix from 100 to 200 kg N/ha per year (Stevenson 1982). Often state reclamation laws require the use of native species and will not allow introduced legume species. However, at the Stillwater Mine site, sweet clover has proven to be a valuable forage species which holds up well under intense grazing pressure by the bighorn sheep of the area.

Plants need relatively large amounts of phosphorous but the amount available is often low in soils. Seedling development is very restricted when soils are deficient in this element. Despite adequate applications of nitrogen, grasses usually exhibit very limited growth on phosphorus deficient soils (Follet et al. 1981). Legumes which are helpful in reestablishing pathways for rapid nitrogen cycling (Reeder 1990) are also sensitive to phosphorous availability. They require larger amounts of this nutrient than most other plant species.

Potassium, another important macro nutrient, is necessary for normal lignin and cellulose development in plants. Cellulose and lignin contribute strength and stiffness to plant cell walls (Follet et al. 1981). Potassium also encourages root development. This is an important factor for plants on sandy soils with low water holding capacity. Plants with an abundance of roots are able to utilize soil moisture efficiently. This improves their drought resistance. Fortunately, young western soils are rarely lacking adequate quantities of this element.

Organic Matter and Soil Biota

Decomposition and mineralization of organic matter provides a steady supply of nutrients especially nitrogen and phosphorus for plants (Smith et al. 1987). The organic fraction of soil holds over 99 percent of the soil nitrogen supply. When the organic matter content of the surface soil is adequate, nitrogen fertilization of disturbed soils is not necessary (Munshower 1994, DePuit and Coenenberg 1979, Rennick et al. 1984). Organic matter in soils also enhances the water holding capacity by increasing water absorption and retention (Brandt and Hendrickson 1991). This is especially important in sandy or skeletal soils. Addition of organic matter to clayey textured soils often reduces soil crusting (Parady 1981) and increases infiltration and percolation rates.

Organic matter consists of the decaying remains of plants and animals as well as living microorganisms. The residues may be fresh material on the ground surface, older partially decomposed particles in the soil, or materials which have been broken down to smaller organic molecules. Humus, the primary constituent of organic matter, is produced as plant residues decompose. Soil organisms are an important component of organic matter and include bacteria, fungi, insects, earthworms and small animals (Smith et al. 1987). The functions of these organisms include fragmentation of plant matter, soil mixing, and releasing plant nutrients such as nitrogen, phosphorous and sulfur.

A group of microorganisms key to revegetation success are the mycorrhizal fungi. The structures (mycorrhizae) formed by these fungi increase the surface area of plant roots. This increases the area available to the plant for the absorption of water and nutrients (Raven et al. 1981). This enhanced nutrient absorption potential created by the mycorrhizae can be a critical factor for plants on reclaimed soils of low-fertility. Many plants seem to grow normally when they are well supplied with essential elements, even if mycorrhizae are lacking; however, if the essential elements are limited, plants grow poorly or not at all when they lack mycorrhizae (Brady 1974). The role of mycorrhyzae in the direct transfer of phosphorous from the soil to the roots of plants has been documented (Raven et al. 1981).

Many forest trees are dependent on mycorrhizal associations for normal growth under natural conditions. Reid and Grossnickle (1978) found that tree seedlings transplanted to soils barren of mycorrhizal fungi generally did not survive unless the seedlings or soil was inoculated with the fungi. Seedlings can be inoculated in the nursery and transplanted to the reclamation site (Cordell et al. 1987). In a study by Sopper and Seaker (1987) municiple sewage applied to mine spoils in Pennsylvania facilitated the rejuvenation of microbial populations including mycorrhizae in the spoils.

Soil microbial parameters have been used to study the rate of recovery of reclaimed land. Enzyme activities, ATP levels, and soil respiration have been used by Stroo and Jencks (1982), Schafer et al. (1979), and Visser et al. (1983) to describe the development of microbial activities in mine soils. Allen (1984) studied the effects of disturbance on mycorrhizae and concluded that any practice which sustained the plant mycorrhizae relationship enhanced vegetation establishment

Coversoil, material which is likely to be lacking in organic matter, including microorganisms, should be amended to encourage mycorrhizae populations as well as populations of other microoorganisms. For any reestablishment of vegetation it is essential that microbial activity is restored to ensure carbon and nutrient turnover. Organic matter and fertilizer will greatly enhance the reestablishment of microbial populations (Fresquez et al. 1986).

Mulches

Successful revegetation of coarse soils materials requires the application of mulch at the time of seeding in order to hold the soils as well as the seed in place. Mulches are most often organic materials applied to the surface of a disturbance after seeding. Mulches, when incorporated, are organic amendments and create pronounced impacts to soil structure, infiltration, cation exchange capacity and nutrient cycles (Munshower 1994). At the Stillwater site where high winds are common year round, mulches hold the seed in place and retain moisture for seedling/plant uptake. Kay (1978) noted that mulches serve to enhance infiltration of water into the soil and moderate surface temperatures. They also provide physical protection from the kinetic energy of raindrops and create minidams which help to hold water where it falls thereby encouraging infiltration and minimizing runoff (Duell 1989). In a study by Kay (1974) the use of straw mulch increased plant establishment in decomposed granite. Adverse effects of straw mulch include the possible immobilization of nitrogen during decomposition (Berg 1980), interception of light and the creation of a possible physical barrier to seedling development.

Biosol - An Organic Fertilizer

Biosol is a slow release organic fertilizer product consisting of dried granular fungal mycelial material. It is more than 70% organic matter and contains major and minor nutrients. While it has been shown to stimulate plant establishment (Naschberger and L. Köck 1983), it is more costly than mineral fertilizers.

Most of the research conducted with this material has been carried out in alpine environments. The terrain in these areas is usually very steep and soils are highly erodible when disturbed. One study comparing materials for erosion prevention at high altitudes (Badawy and Schönthaler 1983) found that Biosol increased the effectiveness of protection against soil erosion. This was due to the fact that within one or two days after application a dense network of hyphae developed in the top layer of the soil (1-2 cm). These hyphae retard soil erosion by water. A study by Glatzel and Fuchs (1986) compared Biosol to mineral fertilizer when applied to surface soils planted with spruce seedlings. The Biosol treated seedlings responded with better growth, a more complex root system, and needles had a deeper green color than plants receiving only mineral fertilizer. High altitude abandoned mine sites in Idaho's Payette National Forest were hyrdroseeded and fertilized with Biosol in 1992. Rohlman (1993) reported high seed germination and excellent plant survival on these sites which were topsoil deficient.

MATERIALS AND METHODS

Site Description

The Stillwater Mine is an underground platinum and palladium mine located in the Stillwater River valley 8 km south of Nye, Montana, and approximately 130 km south west of Billings, Montana (Figure 1). The mine is situated in the Beartooth Mountains. The elevation at the mine ranges from 1,525 m above mean sea level (msl) at the Stillwater river to 1,920 m above msl at the uppermost adit. The mine site including portal areas, mill, and tailings pond, is situated in an area formerly occupied by chromium milling and mining activities. Bighorn sheep have historically used this area as a winter range because high winds reduce snow cover to a minimum on these exposed slopes.

Conventional mining methods are used to drive adits and extract ore at the Stillwater Mine but three of the major access adits were driven with a tunnel boring machine (TBM) in 1988 and 1989. The waste rock produced by the TBM contains a greater amount of fine ground rock than conventionally produced waste rock. The test plots described in this text were constructed of this TBM waste rock. They are located east of the Stillwater River on level terrain which had not been disturbed by mining activities (Figure 1).

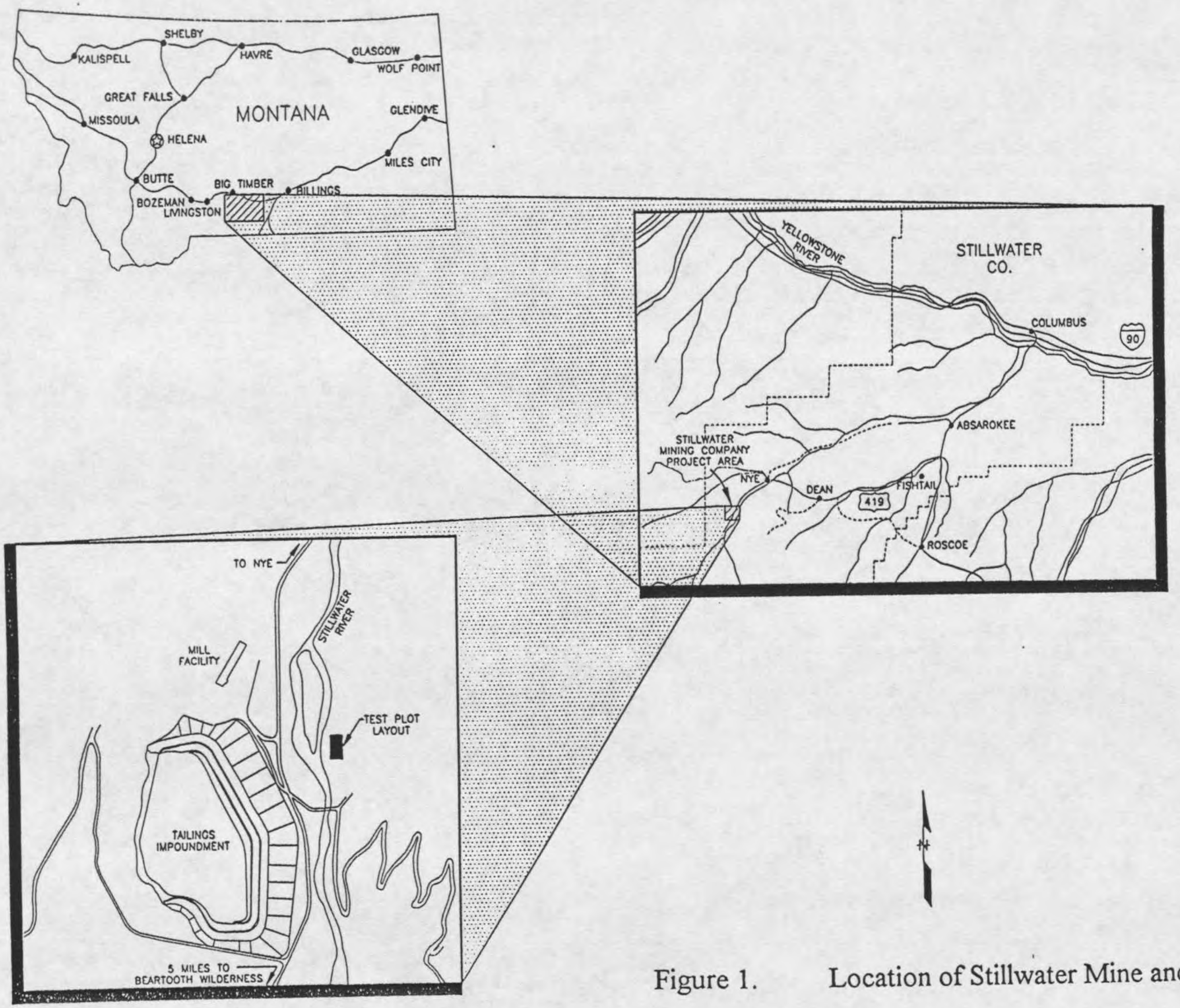


Figure 1. Location of Stillwater Mine and Test Plots

Field Plot Design

In December 1988, several yards of TBM cuttings were hauled, dumped and graded to approximately 60 cm thick in a near level, undisturbed area immediately east of the Stillwater River (Figure 1). The study plots were placed on these graded materials. The field plot design was a split plot with complete randomized blocks (Snedecor and Cochran 1978) in three replications, with five mulch treatments and three fertilizer sub-treatments. Plots were staked, 183 cm on each side with a 183 cm alley between replications. One seed mix comprised of drought tolerant species adapted to the site was seeded on all plots during December 1988.

The plot configuration is shown on Figure 2 and mulch treatments and fertilizer subtreatments are identified in Table 1.

Table 1. Mulch treatments and fertilizer sub-treatments applied to TBM cuttings.

Main Plot ID	Mulch	Application Rate
WF-1	Wood Fiber	2,800 kg/ha + 110 kg/ha tackifier
WF-2	Wood fiber	5,600 kg/ha
Grass	Pelleted Grass Matter	2240 kg/ha
Straw	Wheat Straw	2240 kg/ha
None	No Mulch	
Sub-Plot ID	**Fertilizer**	**Application Rate**
1	Mineral (27-18-0)	220 kg/ha
2	Biosol	1120 kg/ha
3	Biosol plus P_2O_5	1120 kg Biosol/ha + 45 kg P_2O_5/ha

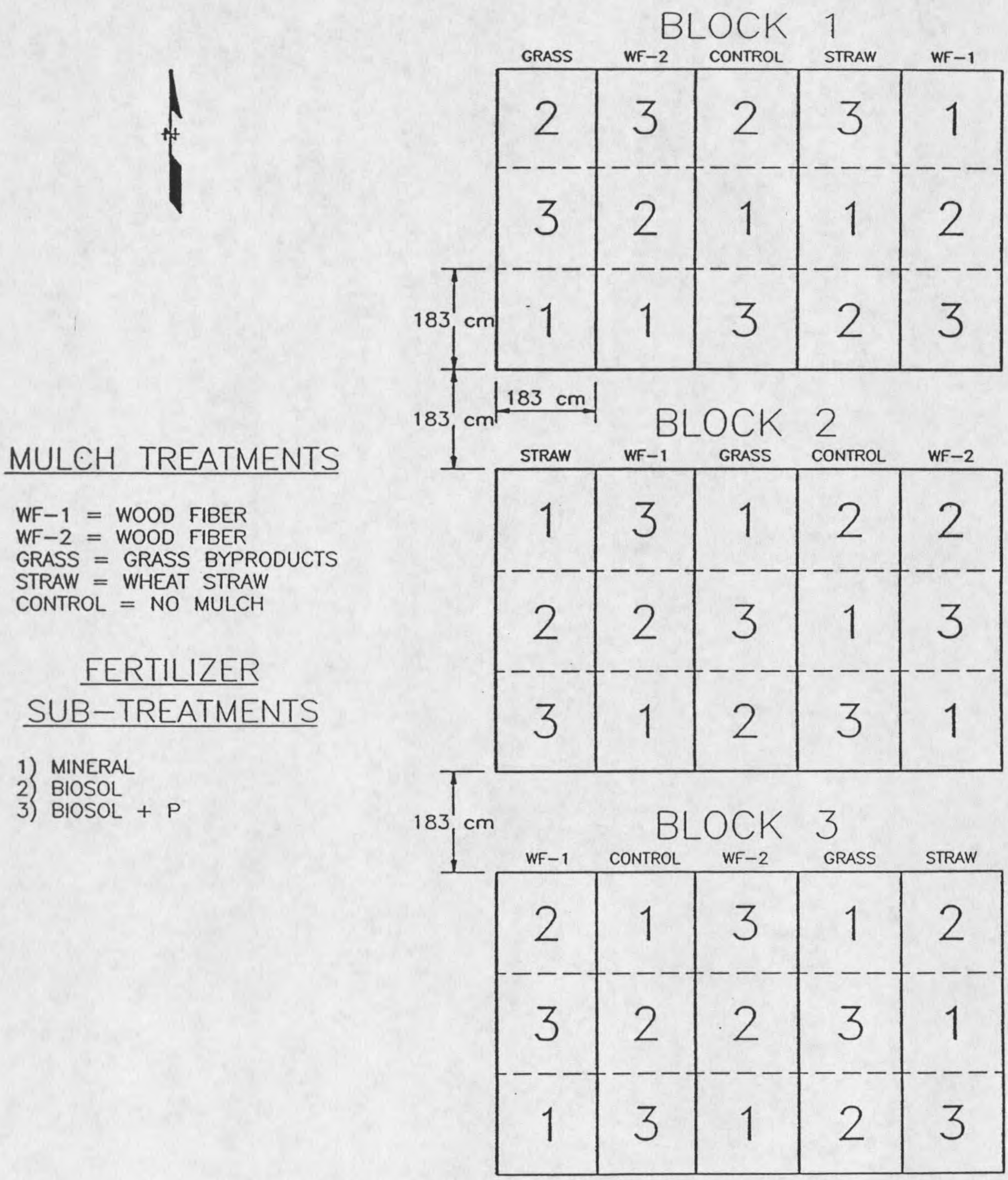


Figure 2. Field plot design implemented on the TBM cuttings

Mulch Treatments

Three different types of organic mulches were used on the test plots. Two of these mulches, the wood fiber and the pelleted grass were applied as hydromulch. The wood fiber, Silva-Fiber, has been used successfully at the Stillwater site with only minor problems caused by high winds. It was applied at two different rates (2,800 kg/ha and 5,600 kg/ha) with the addition of a tackifier to provide added protection against wind and water erosion. The second mulch consisted of sun-cured grass seed, stems and hulls which is pulverized, steam heat-treated, concentrated and pelletized. This pelletized mulch was applied at one rate (2,240 kg/ha). A tackifier was also used with this mulch.

Straw was applied as a fourth treatment. It was applied by hand at approximately 2240 kg/ha and crimped into the surface of the cuttings by tracking with a small dozer. This technique had previously been used on level and gently sloping areas of the mine site. The straw used on the test plots was wheat straw secured from a local source. A seeded and fertilized control plot with no mulch application was the fifth treatment.

Fertilizer Sub-treatments

Fertilizer application rates were based on laboratory analysis of the TBM cuttings. The plant available macronutrients in the TBM cuttings were compared to plant nutrient needs for emergence and establishment in order to arrive at estimated appropriate application rates of the selected soil fertilizers. All fertilizer treatments were broadcast by hand and incorporated into the surface with a fixed tooth harrow.

A mineral (inorganic) fertilizer with an N-P_2O_5-K_2O content of 27-18-0 was incorporated at a rate of 220 kg/ha. Ammonium nitrate and diammonium phosphate were blended to produce this mix.

Biosol, a plant growth stimulator developed in Austria, consists of 70 % organic matter (Rocky Mountain Bio-Products). The source of organic material in Biosol is dried granular fungal mycelial material, a by-product from the manufacture of penicillin. The composition of Biosol is 90 percent dried biomass (dry mycelium) and 10 percent potassium-magnesia. The nutrient content is 6 % nitrogen, 1 % P_2O_5 and 3% K_2O.

Two subtreatments of Biosol were incorporated at 1120 kg/ha. One was incorporated with additional phosphorous (diammonium phosphate) at 45 kg P_2O_5/ha (Table 1). The other treatment was applied without any additional phosphorous.

Seed Mix

Native plant species and those suitable for establishing in the sandy loam texture of the TBM cuttings were included in the species mix (Table 3) seeded on the test plots. Other factors taken into account when choosing the species were forage value and ease of establishment.

Indian ricegrass (*Oryzopsis hymenoides),* a cool season perennial bunch grass, is well established in the Stillwater valley. It is an excellent forage plant and is one of the first perennial grasses to become reestablished on sandy sites after disturbances (Taylor and Lacey 1994). Indian ricegrass is especially abundant in areas of sandy soils where wind has deposited chromium tailings from the chromium ore processing of the 1940's. These soils

Table 2. Plant species seeded on TBM cuttings

Scientific name*	Common name	Pure live seed/ m^2
Grasses		
Agropyron dasystachyum	Thickspike wheatgrass "Critana"	107
Agropyron spicatum	Bluebunch wheatgrass "Secar"	75
Agropyron trachycaulum	Slender wheatgrass "Revenue"	65
Orzyopsis hymenoides	Indian ricegrass	75
Calamovilfa longifolia	Prairie sandreed	129
Festuca ovina	Sheep fescue	86
Forbs		
Linum lewisii	Blue flax	75
Meliolitus alba	White sweet clover	86

* Scientific names taken from Hitchcock and Cronquist 1973.

are also vegetated by prairie sandreed (*Calamovilfa longifolia*) and western wheatgrass (*Agropyron smithii*). Thickspike wheatgrass (*Agropyron dasystachyum)* was seeded instead of Western wheatgrass because of the coarse texture of the wastes. Bluebunch wheatgrass *(Agropyron spicata*) and sheep fescue (*Festuca ovina*) were added to the seed mix because they are the dominant grass species on undisturbed native grasslands of the study area. Slender wheatgrass (*Agropyron trachycaulum*) was seeded as a nurse crop. It develops early but dies out of the community as the other perennial grasses mature.

White sweet clover (*Meliolitus alba*) was included in the mix as a source of nitrogen and for forage value. This clover has been used in revegetation seed mixes at the Stillwater

Mine where it has performed well as a soil stabilizer and as a reliable source of forage for the bighorn sheep native to the area. Blue flax *(Linum lewisii)* was added to the seed mix to increase plant diversity and enhance the appearance of the plant community.

Seeding took place during December so that the germinating seeds could take advantage of moisture that accumulated during the winter storms.

Characterization of TBM cuttings

A grab sample of the TBM cuttings was collected from a waste pile. Due to the nature of the TBM cuttings, i.e. composed of freshly ground and unweathered quartz monzanite, plant available nutrients were assumed to be low in these materials. In order to define the plant available nutrients, a sample of the fine earth portion of the TBM cuttings was chemically and physically characterized. The sample was screened to determine the amount of coarse fragments. Analytical parameters, laboratory procedures, and references for these analyses are summarized in Table 3.

Field Plot Implementation and Vegetation Monitoring

During December 1988, the plots were ripped, seeded, fertilized and mulched. After the cuttings were graded to near level, a dozer ripped the surface to a depth of 7 to 15 cm. The plots and subplots were staked, fertilizer sub-treatments broadcast by hand, and seed applied with a hydroseeder. This was accomplished by adding seed for the entire plot layout to 2,800 liters of water and applying this mixture to the site. The fertilizer and seed were

Table 3. Methods of chemical and physical analysis of TBM cuttings.

Parameter	Procedure	Reference
pH	saturated paste	US Salinity Staff (1954), Meth 21a
Ammonium Nitrogen as N	KCl extraction	Thomas (1982), Meth.84-2
Nitrate as N	potassium choride ext.	Thomas (1982), Meth. 84-2
Phosphorous as P	Olsen Method ($NaHCO_3$)	Thomas (1982), Meth. 73-4
Available K	ammonium acetate extraction	Thomas (1982), Meth. 71-3
Cu, Cr, Fe, Mn, Zn	DTPA extraction	Follet and Lindsay (1970)
Ca, Mg, Na	ammonium acetate ext.	Thomas (1982)
Sodium adsorption ratio (SAR)	$Na/[(Ca+Mg)/2]^{1/2}$	US Salinity Staff (1954)
Conductivity	water saturated paste extraction	Sandoval and Power (1977)
Percent moisture at saturation	saturated paste	Bower and Wilcox (1965)
Particle size distribution	hydrometer, sieve, screen	Day (1965)

incorporated into the cuttings (2 to 3 cm deep) by pulling a fixed tooth harrow over the plots. Mulch treatments on the plots were applied on top of the seed and fertilizer sub-treatments.

Plant canopy cover and production were measured in mid July 1989, during the first growing season. Percent cover was estimated in two 20 x 50 cm frames (Daubenmire 1959) randomly placed within each plot. Production was determined by clipping the above ground biomass within these same frames. Vegetation was grouped by plant life form for cover estimation and biomass determination. The plant materials were oven dried at 60° C for 72 hours prior to weighing.

During July, 1994, five years after the first episode of monitoring, vegetation measurements were made on the plots for a second time. Cover and production data were collected in the same manner as in 1989.

The cover and production data from 1989 and 194 were analyzed using a two-way repeated analysis of variance (ANOVA) on two factors. Multiple mean comparisons were based on Least Significant Differences (LSD) at a significance level of 0.10. Statistical analyses were performed using the MSUSTAT statistical package (Lund 1993). ANOVA and LSD tables are included in Appendix B.

RESULTS AND DISCUSSION

Characterization of TBM Cuttings

Chemical and physical testing results of the soil fraction of the TBM cuttings are found in Table 4. Chemical analysis of macronutrients indicate very low quantities of nitrogen (2.31 ppm) (Sabey 1987) and phosphorous (0.26 ppm) (Energy Laboratory 1989). Potassium levels (100 ppm) were low but were not supplemented by fertilization. The pH of the cuttings was 7.4. Soils having a pH in the range of 6.0 - 8 favor nitrogen and phosphorous availability and microbiological activity for nitrogen fixation. (Tucker et al.1987). Plant micronutrients were adequate (Follet and Lindsey 1970) with the exception of zinc which was low for a soil material. This chemistry is explained by the mineralogy of the quartz monzanite which may be rich in metal bearing minerals (Hyndeman 1972).

Soil texture influences plant growth by its direct effect on water infiltration, soil aeration, cation exchange capacity and erodibility. The soil fraction (< 2mm) of the TBM cuttings falls in the texture classification of a loamy sand. The coarse texture of the material and high coarse fragment content may result in rapid water drainage and low water holding capacity. The percent moisture at saturation (18.8 %) is considered low and below the recommended range of 25 to 80 % for coversoil materials used at western coal strip-mines (Schafer 1979). For coarse materials, the saturation percentage is approximately two times field capacity (1/3 bar water retention) and four or more times the wilting point (Merrill et al. 1987). Comparable values for TBM cuttings are, therefore, field capacity - 9.4 % and wilting point - 4.7 %.

Table 4. Chemical and physical characteristics of TBM cuttings.

Parameter	Result
pH	7.4
N as Ammonia	0.31 ppm
Nitrate	2.0 ppm
Phosphorous as PO_4	0.26 ppm
Available K	100 ppm
Copper	0.37 ppm
Chromium	<0.005 ppm
Iron	58.4 ppm
Manganese	2.4 ppm
Zinc	0.30 ppm
Calcium	3.3 meq/l
Magnesium	2.0 meq/l
Sodium	1.94 meq/l
Sodium Adsorption Ratio	1.19
Conductivity	0.05 mmhos/cm
Percent gravimetric moisture at saturation	18.8 %

Size Distribution of Soil Fraction	(<2mm particle dia.)
Sand (0.05 - 2 mm)	72.5 %
Silt (0.002 - 0.5 mm)	23.9 %
Clay (<0.002 mm)	3.6 %
Rock fragment Content (>2 mm)	46 % of total

Vegetative Response

Cover

Cover is an important factor in successful revegetation. It is an indicator of how much erosion protection the soil surface receives from plant leaves. In the case of the TBM cuttings, which are very light colored, it reduces the visual impact of these materials, allowing them to blend with the natural surroundings. Percent plant cover data for 1989 and 1994 are presented in Table 5. The only significant difference observed among the mulch treatments was the greater amount of annual grass cover on the "straw" mulched site compared to the others in 1989. This effect is explained by the domination of the plots by annual grains during the first growing season. Seed of the annual grasses were derived from the cereal grain mulch.

The subplots treated with Biosol + P yielded significantly greater perennial cover during 1989. Annual forb cover was significantly greater on the Biosol treatment in 1989. During 1994 the Biosol + P treatments again yielded significantly greater cover of perennial grass. The mineral fertilizer treatments in 1994 yeilded significantly higher perennial forb cover than the Biosol + P. No significant differences were noted among the 1989 annual grass or 1994 annual forb data.

The 1994 cover data in Table 5 show a tendency toward increased plant cover for either the mineral fertilizer or Biosol + P treatments. These differences are not always significant but they are consistent.

Table 5. Mean plant cover (%) 1989 and 1994.

		1989						1994			
Mulch Treatment	N	Perennial Grasses	Perennial Forbs	Perennial (Total)	Annual Forbs	Annual Grass	Total *	Perennial Grasses	Perennial Forbs	Annual Forbs	Total Cover
Wood Fiber 1	9	78 a **	< 1 a	78 a	7 a	< 1 a	85 a	68 a	33 a	1.0 a	102 a
Wood Fiber 2	9	85 a	2 a	87 a	1 a	< 1 a	88 a	60 a	26 a	0.5 a	87 a
Pelleted grass	9	84 a	< 1 a	85 a	6 a	< 1 a	92 a	70 a	19 a	0.1 a	90 a
Straw	9	56 a	< 1 a	57 a	7 a	15 b	79 a	74 a	23 a	0.6 a	97 a
No Mulch	9	86 a	2 a	88 a	13 a	< 1 a	101 a	59 a	32 a	0.2 a	91 a
Fertilizer Sub-treatment											
Mineral	15	42 a	<1 a	42 a	3 a	3 a	49 a	63 a	32 b	.4 a	95 ab
Biosol	15	84 b	<1 a	84 b	15 b	2 a	101 b	61 a	25 ab	.7 a	87 a
Biosol + P	15	108 c	2 b	110 c	3 a	5 a	118 b	75 b	23 a	.5 a	98 b

* Total cover includes all perennial grasses , perennial and annual forbs, and annual grass.

** Means followed by the same letter in the same column indicate no significant difference (P=0.10) .

Annual pioneer species (most often annual forbs) are usually the first plants to naturally invade disturbed ground. These plants rapidly decrease as the seeded native perennial species increase. Average cover supplied by annual forbs comprised one to 15 percent of total cover on the plots during 1989. During 1994 annual forbs were noted on less than twenty percent of the 45 plots (Appendix A) and at less than a trace when found.

A fertilizer control was not used in this study but observations of the untreated alleys between the blocks which had been seeded but not fertilized, show very sparse vegetative cover when compared to the treated plots. This can be seen in the photo taken from the air during July of 1990 (Figure 3).

Figure 3. July 1990 aerial view of test plots. North is toward bottom of photo.

Production

Raw biomass production data are presented in Table 9, Appendix A. Due to the difficulty distinguishing between the wheatgrasses in the field, the plants were grouped into perennial grasses and perennial or annual forbs for analysis. The average dry weight for perennial grasses, perennial forbs, annual forbs and total production for 1989 and 1994 are summarized in Table 6. For the year 1989 this table includes data for annual grasses. Annual grasses did not grow on the plots in 1994 and, therefore, they were not a component of the plant communities in this year. The total production numbers reflect all forbs, grasses and cereal grains present on the plots.

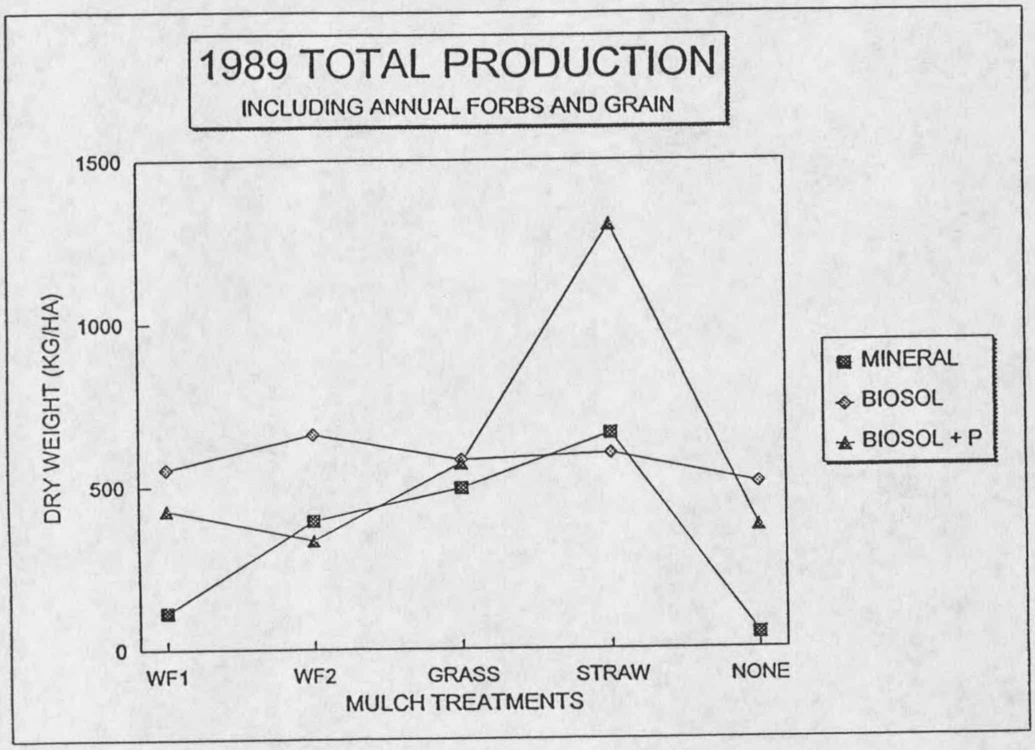
No significant effects among mulch treatments were observed in the perennial plants during either 1989 or 1994 (Table 6). Annual grass production during 1989 was significantly increased by the application of straw mulch. It is obvious that the non significant increase in total production on the straw mulch treated plots was a result of the annual grasses present on those plots during the first growing season. The presence of this cover crop may have also resulted in the decrease in perennial production during 1989 by competing for moisture, sunlight, nutrients, etc. These effects were not observed during 1994. The mean total production data for 1989 and 1994 are displayed on Figures 4 and 5, respectively. Perennial grass and perennial forb production in 1994 are compared on Figure 6.

Table 6. Mean plant production (kg/ha) 1989 and 1994.

		1989						1994			
Mulch Treatment	N	Perennial Grasses	Perennial Forbs	Total Perennial	Annual Forbs	Annual Grass	Total * Production	Perennial Grasses	Perennial Forbs	Annual Forbs	Total Production
Wood Fiber 1	9	343.4 a **	9.1 a	352.4 a	12.4 a	<0.01 a	364.8 a	1362 a	490.8 a	15.4 a	1868 a
Wood Fiber 2	9	414.2 a	6.5 a	420.7 a	42.4 a	<0.01 a	463.1 a	1643 a	267.7 a	6.3 a	1917 a
Pelleted grass	9	531.4 a	5.8 a	537.2 a	10.7 a	<0.01 a	547.9 a	1763 a	363.4 a	0.1 a	2127 a
Straw	9	301.4 a	2.9 a	304.3 a	115.6 a	434.3 b	854.0 a	1492 a	265.3 a	5.3 a	1762 a
No Mulch	9	273.2 a	1.6 a	274.8 a	35.9 a	<0.01 a	310.5 a	1141 a	432.6 a	1.5 a	1575 a
Fertilizer Sub-treatment											
Mineral	15	258.8 a	5.5 a	264.3 a	30.7 a	46.6 a	341.6 a	1330 a	528.4 b	7.8 a	1866 b
Biosol	15	488.4 c	5.5 a	493.8 c	26.8 a	59.7 a	580.4 a	1001 a	230.2 a	5.4 a	1236 a
Biosol + P	15	371.1 b	4.5 a	375.5 b	72.6 a	154.3 a	602.2 a	2110 b	333.3 a	3.9 a	2447 c

* Total production includes all perennial grasses, perennial and annual forbs, and annual grass

** Means followed by the same letter in the same column indicate no significant difference (P=0.10)



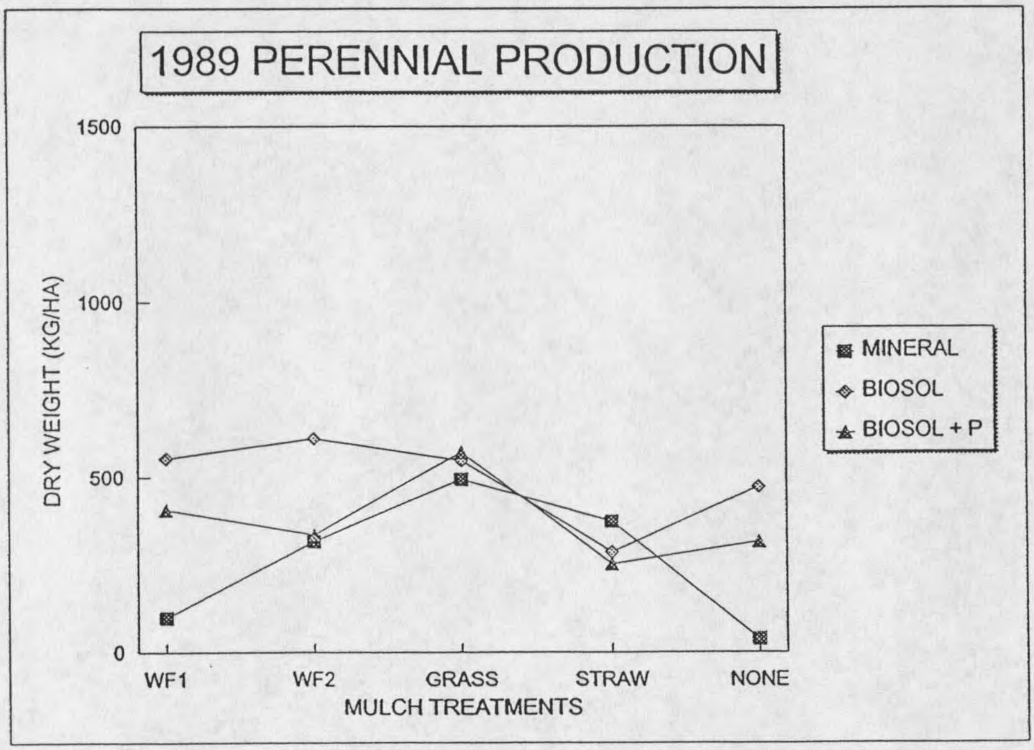
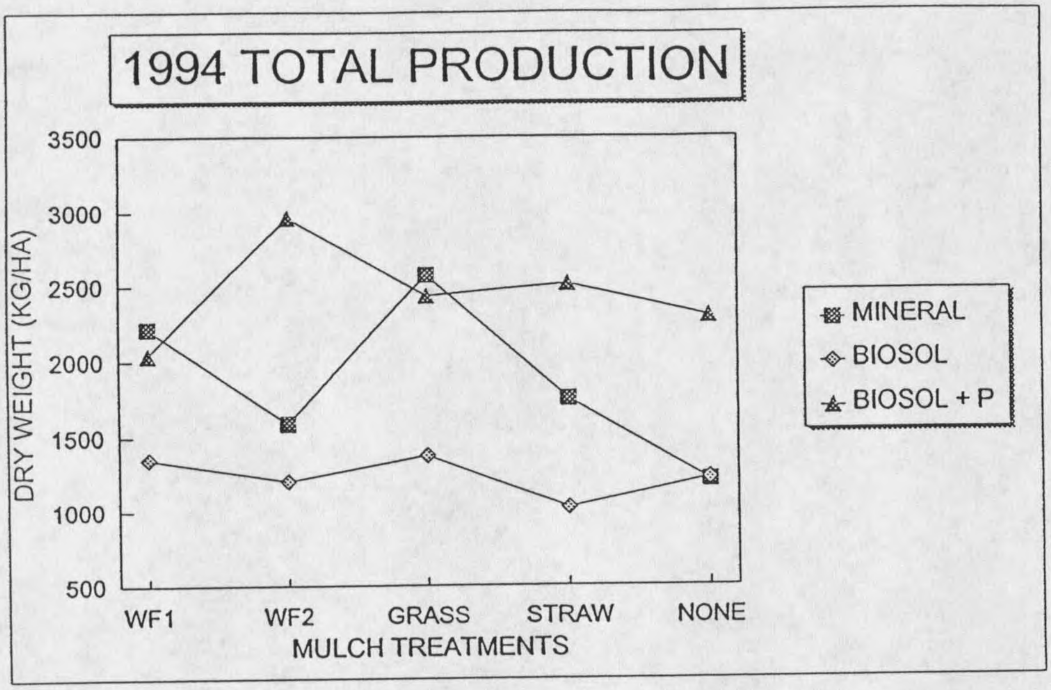


Figure 4. Total and perennial plant production in 1989.



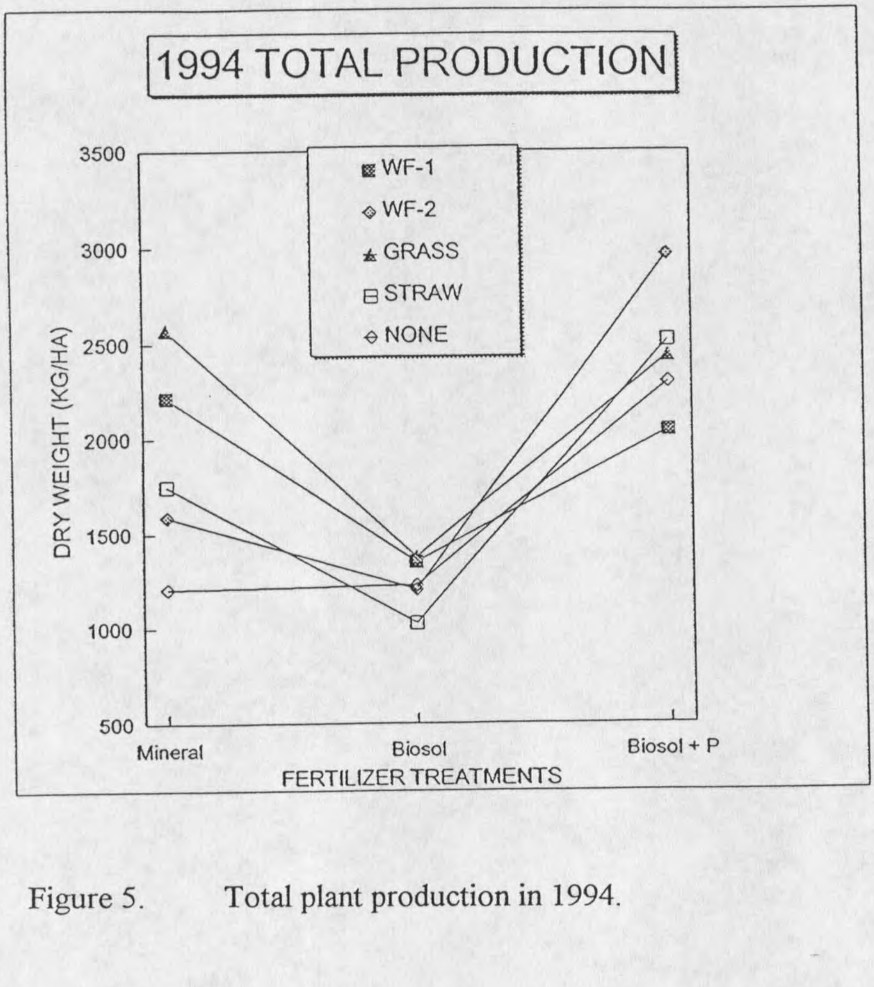
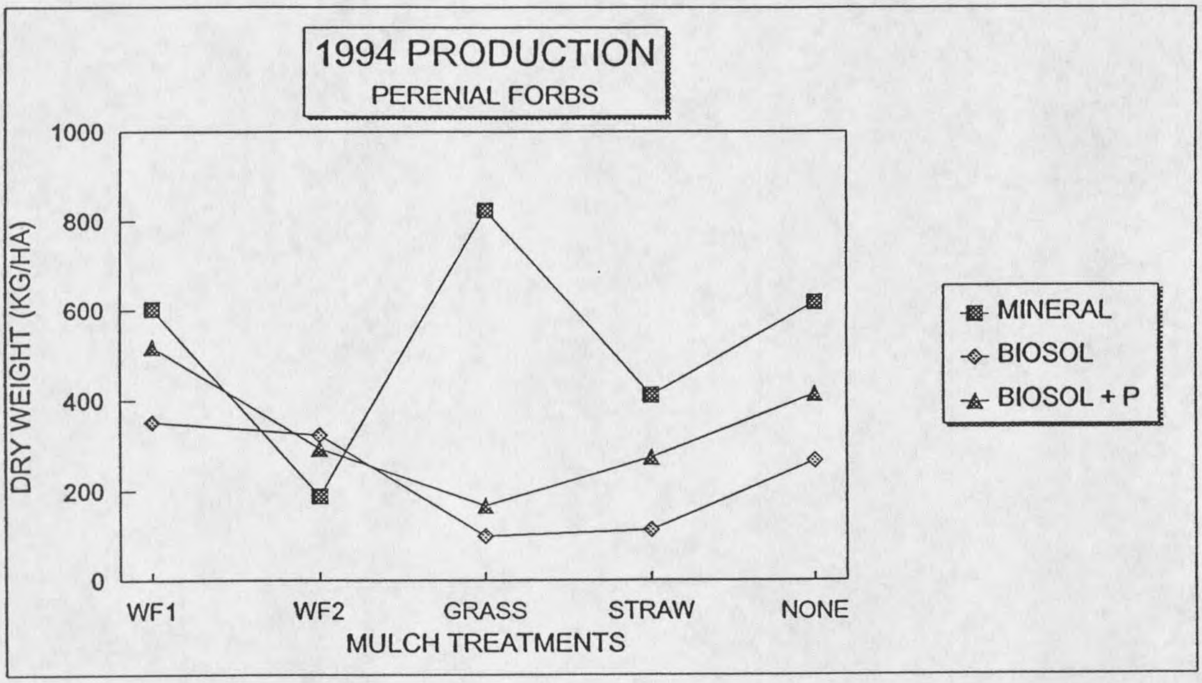


Figure 5. Total plant production in 1994.



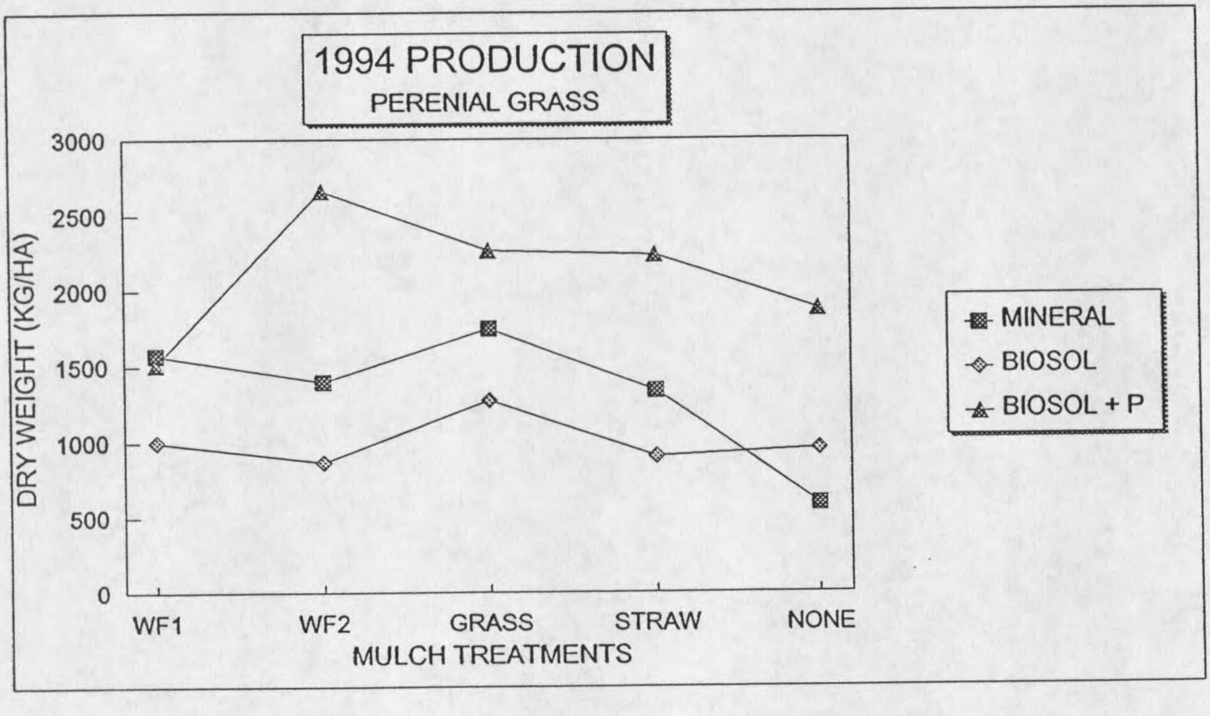


Figure 6. Perennial grass and forb production in 1994.

In general, there were significant differences among the fertilizer sub-treatments. Plant responses in 1994 were enhanced by the addition of fertilizer sub-treatments which included phosphorous (mineral and Biosol + P) (Table 6). In 1989 production of perennial grasses on the plots treated with Biosol was slightly higher than production on the Biosol + P or mineral fertilizer treated plots. In 1994 perennial grass and total production were significantly greater for the Biosol + P treatment. The 1994 Biosol only treatment showed the lowest production in all plant categories except the annual forbs. This change in plant response from 1989 to 1994 is an indication of the importance of phosphorus in long term perennial grass production when these nutrient deficient cuttings are used as a soil resource.

Production for all perennial plant categories was higher during 1994 than 1989 (Table 7). Perennial production data for 1994 also included unseeded native species which had established on the plots. These species included *Agropyron smithii, Artemesia tridentata, Oxtropis* sp. and *Rose woodsii.* Nevertheless, the production of perennial grasses increased dramatically from 1989 to 1994. Increases ranged from 2 to 16 times.

In 1989 the combined effect of pelleted grass and the three fertilizers produced an increase in total and perennial grass production compared to the other mulch/fertilizer treatments (Table 7). Plant response to Wood Fiber 2 and fertilizer was almost as great as plant production response to the pelleted grass and fertilizer. These phenomena emphasize the importance of organic enrichments to short and long term plant response.

Table 7. Total plant production (kg/ha) 1989 and 1994.

		1989				1994		
Mulch Treatment	Fertilizer Sub-treatment	TOTAL PERG	TOTAL PERF	TOTAL PRODUCTION	TOT. PER. PRODUCTION	TOTAL PERG	TOTAL PERF	TOTAL PRODUCTION
Wood Fiber 1	Mineral	98.00	0.20	113.70	98.20	1573.50	603.33	2216.00
	Biosol	529.70	24.20	553.80	553.80	997.50	350.67	1348.83
	Biosol + P	402.50	2.80	426.80	405.30	1514.33	518.33	2039.00
Wood Fiber 2	Mineral	308.50	7.20	394.50	315.70	1400.50	187.33	1587.83
	Biosol	610.20	1.00	659.50	611.20	866.67	322.17	1204.67
	Biosol + P	324.00	11.30	335.30	335.30	2661.50	293.50	2958.17
Pelleted grass	Mineral	476.50	16.80	493.30	493.30	1747.33	824.17	2571.50
	Biosol	547.30	0.50	579.80	547.80	1276.83	99.33	1376.50
	Biosol + P	570.50	0.00	570.50	570.50	2265.33	166.67	2432.00
Straw	Mineral	373.80	3.20	660.70	373.00	1337.83	410.17	1748.00
	Biosol	283.50	1.20	599.80	284.70	905.17	112.33	1026.00
	Biosol + P	247.00	4.30	1301.50	251.30	2231.83	273.50	2512.67
No Mulch	Mineral	37.20	0.30	45.80	37.50	589.50	617.00	1206.50
	Biosol	471.20	0.50	508.80	471.70	957.17	266.33	1225.17
	Biosol + P	311.30	3.80	376.80	315.20	1876.83	414.33	2294.00

PERF = Perenial forbs
PERG = Perenial grasses

Field Observations

Evidence indicating wildlife utilization of the seeded species was observed during collection of the production and cover data in 1989 and 1994. Plants appeared to have been foraged by deer or bighorn sheep. Spotted knapweed was observed on the plots in 1994.

A list of all plant species observed on the plots in 1994 is included in Appendix C (Table 30).

CONCLUSIONS AND RECOMMENDATIONS

The applications of mulch and fertilizer on the Stillwater Mine TBM cuttings produced a viable stand of vegetation during the five year period of this study. The absence of organic matter and plant nutrients in the untreated cuttings elicited a positive response to all combinations of the amendments (treatments and sub-treatments).

The only significant difference among the plant responses to the mulch treatments was observed in 1989. Significant effects of only the straw mulch were measured during this first growing season. The annual grasses derived from seed in the straw mulch increased total production and cover but the growth of perennial grasses was reduced on these treatments. This effect had been lost by 1994. No annual grasses were found growing on the plots in 1994 because they could not reseed themselves.

A comparison of the fertilzer sub-treatments indicated that plant growth was enhanced by the application of additional phosphorous during 1989 and this effect was still exhibited by the vegetation in 1994. It may be inferred that large quantities of phosphorous are necessary to maintain high plant growth rates on the TBM materials. Even Biosol with up to 1 % phosphorous required augmented supplies of this element to support maximum plant growth.

Results of this field study suggest that the TBM cuttings produced at the Stillwater Mine will sustain vegetation for at least five years when organic matter, nitrogen and phosphorous are added to the TBM derived coversoil. Further research into the effectiveness of Biosol fertilizer without the use of mulches may be warranted, but this study indicated that enhanced plant growth resulted when organic materials were added to the Biosol.

The fertilizer sub-treatments were incorporated into the surface of the TBM cuttings for this field study. This was easily accomplished since the test plot terrain was level and accessible with machinery. In order to revegetate steep inaccessible slopes it is necessary to hydraulically apply fertilizer and mulch to the surface of the slope. This application method has been successful using only Biosol and no mulch on marginal soils in the Payette National Forest (Rohlman 1993). Benefits of this amendment will not be as pronounced when it is only surface applied as opposed to incorporated into the soil.

Research on the importance of organic matter incorporated into minesoils has repeatedly proven the ability of such amendments to increase soil porosity, infiltration, water holding capacity and nutrient reserves of these materials. The incorporation of locally available organic amendments such as manure or sewage sludge should be evaluated. The economic benefits of using materials readily available at a disturbed site must be weighed against the growth enhancing properties of more expensive amendments. This research indicated that almost any source of organic matter will produce comparable results over a five year period if mineral fertilizers are also added to the root zone materials. The purchase of expensive amendments does not appear to be warranted when TBM cuttings are used as a surface covering material at this study site.

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APPENDICES

APPENDIX A

Canopy Cover and Biomass Production Data

Table 8. Grouped canopy cover data 1989 and 1994.

BLOCK	MULCH	FERT	1989 PERG	1989 PERF	1989 ANFO	1989 ANGR	1989 TOTAL PERENNIAL	1989 TOTAL COVER	1994 PERG	1994 PERF	1994 ANFO	1994 TOTAL COVER
1	1	1	61	0	6	0	61	67	72	72	5	149
1	1	2	77	2	5	0	78	83	66	46	0	112
1	1	3	108	0	4	0	108	112	87	42	2	131
1	2	1	39	0	1	0	39	40	51	23	0	74
1	2	2	74	1	4	0	75	79	43	40	1	84
1	2	3	108	2	0	0	110	110	71	8	0	79
1	3	1	88	0	0	0	88	88	75	15	0	90
1	3	2	108	1	7	0	108	115	66	1	1	68
1	3	3	140	1	5	0	141	146	92	0	0	92
1	4	1	37	0	1	22	37	60	55	43	0	98
1	4	2	75	0	7	1	75	83	66	21	0	87
1	4	3	40	0	7	45	40	92	102	18	1	121
1	5	1	1	0	0	0	1	1	40	35	0	75
1	5	2	100	1	35	0	101	135	64	17	0	81
1	5	3	134	7	7	0	141	148	62	25	0	86
2	1	1	36	1	0	0	37	37	75	8	0	83
2	1	2	82	1	3	0	82	85	60	47	1	108
2	1	3	123	1	2	0	124	126	62	36	0	98
2	2	1	48	1	2	0	48	50	81	37	0	117
2	2	2	104	1	4	0	105	109	52	46	0	98
2	2	3	128	7	0	0	135	135	76	27	0	103
2	3	1	32	0	0	0	32	32	43	45	0	87
2	3	2	84	0	33	0	84	117	49	25	0	74
2	3	3	69	1	0	3	70	73	58	25	0	83
2	4	1	81	1	16	6	82	103	83	36	0	119
2	4	2	26	1	0	18	27	45	71	16	1	87
2	4	3	94	4	2	13	99	114	81	19	0	100
2	5	1	15	0	6	0	15	21	47	44	0	91
2	5	2	130	2	3	0	132	135	52	44	0	96
2	5	3	171	2	1	0	173	173	72	52	1	125

Table 8. (Continued) Grouped canopy cover data 1989 and 1994.

BLOCK	MULCH	FERT	1989 PERG	1989 PERF	1989 ANFO	1989 ANGR	1989 TOTAL PERENNIAL	1989 TOTAL COVER	1994 PERG	1994 PERF	1994 ANFO	1994 TOTAL COVER
3	1	1	8	0	13	0	8	21	94	16	1	110
3	1	2	86	1	32	0	86	118	58	17	0	75
3	1	3	124	0	0	0	124	124	41	18	0	59
3	2	1	64	0	0	0	64	64	54	0	0	54
3	2	2	80	0	2	0	80	83	45	27	3	75
3	2	3	124	4	0	0	128	128	71	26	1	98
3	3	1	73	0	0	0	74	74	74	41	0	115
3	3	2	81	0	7	0	81	88	99	0	0	100
3	3	3	86	2	7	0	88	95	79	19	0	98
3	4	1	44	0	5	16	44	64	66	25	0	91
3	4	2	39	0	16	7	39	62	76	8	2	86
3	4	3	68	1	11	10	70	91	64	21	2	87
3	5	1	11	0	0	0	11	11	40	42	0	82
3	5	2	116	3	66	0	118	184	49	22	1	72
3	5	3	103	1	4	0	104	108	106	5	0	111

Table 9. Grouped plant production data 1989 and 1994 (kg/ha).

BLOCK	MULCH	FERT	1989 PERG	1989 PERF	1989 TOTAL PER.	1989 ANGR	1989 ANFO	1989 TOTAL PROD	1994 PERG	1994 PERF	1994 ANFO	1994 TOTAL PROD.	1994 LITTER
1	1	1	193	0	193	0	46	239	1112	1018	107	2237	112
1	1	2	215	69	283		0	283	1370	466	0	1836	113
1	1	3	343	9	351	0	55	406	2158	481	19	2657	228
1	2	1	341	0	341	0	0	341	763	301	0	1064	124
1	2	2	610	1	611	0	145	756	709	364	0	1073	91
1	2	3	476	0	476	0	0	476	1593	22	0	1615	287
1	3	1	581	50	631	0	0	631	1929	657	0	2586	254
1	3	2	790	1	791	0	0	791	1928	7	1	1936	243
1	3	3	657	0	657	0	0	657	4653	0	0	4653	878
1	4	1	360	10	370	0	138	508	919	636	0	1555	132
1	4	2	431	1	432	0	50	482	830	146	0	976	146
1	4	3	412	0	412	1919	824	3154	3264	171	5	3439	275
1	5	1	7	1	8	0	25	33	374	554	0	928	88
1	5	2	365	1	366	0	0	366	1012	104	0	1116	139
1	5	3	131	0	131	0	141	271	1186	286	0	1472	129
2	1	1	90	0	90	0	0	90	949	630	0	1579	115
2	1	2	643	4	647	0	0	647	852	488	2	1342	97
2	1	3	288	0	288	0	8	296	942	662	0	1603	127
2	2	1	450	22	471	0	237	708	2485	261	0	2746	135
2	2	2	746	3	748	0	0	748	1180	258	0	1438	301
2	2	3	337	34	371	0	0	371	3515	363	0	3878	623
2	3	1	251	0	251	0	0	251	768	618	0	1386	92
2	3	2	276	1	277	0	0	277	542	290	0	832	91
2	3	3	311	0	311	0	0	311	667	252	0	919	63
2	4	1	594	0	594	540	15	1149	1688	403	0	2091	292
2	4	2	234	1	235	611	0	845	1151	101	10	1262	227
2	4	3	170	13	183	312	13	508	1930	305	0	2235	410
2	5	1	12	0	12	0	0	12	797	664	0	1460	43
2	5	2	519	1	519	0	112	631	1134	496	0	1630	129
2	5	3	346	0	346	0	0	346	1391	891	9	2291	160

Table 9. (Continued) Grouped plant production data 1989 and 1994 (kg/ha).

BLOCK	MULCH	FERT	1989 PERG	1989 PERF	1989 TOTAL PERENNIAL	1989 ANGR	1989 ANFO	1989 TOTAL PROD	1994 PERG	1994 PERF	1994 ANFO	1994 TOTAL PROD.	1994 LITTER
3	1	1	12	1	13	0	0	13	2660	162	11	2833	204
3	1	2	732	1	732	0	0	732	771	99	0	870	177
3	1	3	577	0	577	0	3	580	1444	413	0	1857	142
3	2	1	135	0	135	0	0	135	954	0	0	954	75
3	2	2	475	0	475	0	0	475	711	345	48	1103	167
3	2	3	160	0	160	0	0	160	2877	496	10	3382	191
3	3	1	599	1	599	0	0	599	2546	1198	0	3744	247
3	3	2	577	0	577	0	96	673	1361	1	0	1362	206
3	3	3	744	0	744	0	0	744	1477	248	0	1725	197
3	4	1	168	0	168	159	0	326	1407	192	0	1599	204
3	4	2	187	2	188	285	0	473	735	91	16	841	181
3	4	3	160	0	160	83	0	243	1502	346	18	1865	202
3	5	1	93	0	93	0	0	93	598	634	0	1232	92
3	5	2	531	0	531	0	0	531	726	199	5	930	122
3	5	3	458	12	469	0	45	514	3054	66	0	3120	302

APPENDIX B

ANOVA and LSD Tables

Table 10. Analysis of variance and least significant difference for percent perennial grass cover, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	476.31	238.16		
Mulch	4	5933.8	1483.4	1.88	.2074
Residual	8	6312.4	789.04		
Fertilizer	2	32930	16465	44.07	.0000
Mulch x Fert	8	15260	1907.5	4.3	.0015
Residual	20	7472.7	373.63		

LSD Analysis

Factor	Identity	Mean Cover
Fertilizer	Mineral	42.53 a
	Biosol	84.13 b
	Biosol + P	108.0 c

Table 11. Analysis of variance and least significant difference for percent perennial forb cover, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	4.311	2.1556		
Mulch	4	13.556	3.3889	1.95	.1957
Residual	8	13.911	1.7389		
Fertilizer	2	30.711	15.356	9.66	.0012
Mulch x Fert	8	24.178	3.0222	1.9	.1163
Residual	20	31.778	1.5889		

LSD Analysis

Factor	Identity	Mean Cover
Fertilizer	Mineral	0.20 a
	Biosol	0.93 a
	Biosol + P	2.20 b

Table 12. Analysis of variance and least significant difference for percent annual forb cover, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	312.13	156.07		
Mulch	4	665.42	166.36	1.84	.2154
Residual	8	724.98	90.622		
Fertilizer	2	1345.6	672.8	5.66	.0113
Mulch x Fert	8	1278.8	159.86	1.34	.2791
Residual	20	2378.2	118.91		

LSD Analysis

Factor	Identity	Mean Cover
Fertilizer	Mineral	3.33 a
	Biosol	14.93 b
	Biosol + P	3.33 a

Table 13. Analysis of variance and least significant difference for percent annual grass cover, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	45.733	22.867		
Mulch	4	1675.2	418.8	16.67	.0006
Residual	8	200.93	25.117		
Fertilizer	2	68.4	34.2	.86	.4365
Mulch x Fert	8	229.6	28.7	.73	.6679
Residual	20	791.33	39.567		

LSD Analysis

Factor	Identity	Mean Cover
Mulch	WF 1	0.0 a
	WF 2	0.0 a
	Grass	0.33 a
	Straw	15.3 b
	None	0.0 a

Table 14. Analysis of variance and least significant difference for percent total perennial cover, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	548.8	274.4		
Mulch	4	6084.8	1521.2	1.89	.2051
Residual	8	6427.2	803.4		
Fertilizer	2	34946	17473	44.81	.0000
Mulch x Fert	8	15682	1960.2	5.03	.0016
Residual	20	7798.7	389.93		

LSD Analysis

Factor	Identity	Mean Cover
Fertilizer	Mineral	42.73 a
	Biosol	84.73 b
	Biosol + P	110.3 c

Table 15. Analysis of variance and least significant difference for percent total cover, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	78.933	39.467		
Mulch	4	2466.8	616.69	1.16	.3971
Residual	8	4263.5	532.94		
Fertilizer	2	39361	19680	39.52	.0000
Mulch x Fert	8	20932	2616.5	5.25	.0012
Residual	20	9959.6	479.98		

LSD Analysis

Factor	Identity	Mean Cover
Fertilizer	Mineral	48.87 a
	Biosol	101.4 b
	Biosol + P	118.3 b

Table 16. Analysis of variance and least significant difference for percent perennial grass cover, 1994 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	120.71	60.356		
Mulch	4	1476.2	369.06	1.08	.4269
Residual	8	2732.2	341.52		
Fertilizer	2	1659.9	829.96	4.08	.0328
Mulch x Fert	8	2797	349.62	1.72	.1558
Residual	20	4073.1	203.66		

LSD Analysis

Factor	Identity	Mean Cover
Fertilizer	Mineral	63.33 a
	Biosol	61.07 a
	Biosol + P	74.93 b

Table 17. Analysis of variance and least significant difference for percent perennial forb cover, 1994 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	1616.9	808.47		
Mulch	4	1316.2	329.06	.83	.5407
Residual	8	3161.5	395.19		
Fertilizer	2	715.6	357.8	2.59	.0996
Mulch x Fert	8	1932.8	241.61	1.75	.1475
Residual	20	2758.9	137.94		

LSD Analysis

Factor	Identity	Mean Cover
Fertilizer	Mineral	32.13 a
	Biosol	25.13 ab
	Biosol + P	22.73 a

Table 18. Analysis of variance for percent annual forb cover, 1994 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	2.1778	1.0889		
Mulch	4	4.5778	1.1444	.82	.5469
Residual	8	11.156	1.3944		
Fertilizer	2	.57778	.28889	.38	.6908
Mulch x Fert	8	9.4222	1.1778	1.54	.2070
Residual	20	15.333	.76667		

Table 19. Analysis of variance and least significant difference for percent total cover, 1994 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	874.49	437.24		
Mulch	4	1471.7	367.94	.43	.7841
Residual	8	6856.2	857.02		
Fertilizer	2	1053.0	526.51	2.65	.0952
Mulch x Fert	8	1867.1	233.38	1.18	.3610
Residual	20	3972.4	198.62		

LSD Analysis

Factor	Identity	Mean Cover
Fertilizer	Mineral	95.81 ab
	Biosol	86.86 a
	Biosol + P	98.05 b

Table 20. Analysis of variance and least significant difference for perennial grass production, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	13840	6919.9		
Mulch	4	384810	96201	1.32	.3416
Residual	8	583640	72955		
Fertilizer	2	395320	197660	12.58	.0003
Mulch x Fert	8	402080	50260	3.2	.0166
Residual	20	314270	15714		

LSD Analysis

Factor	Identity	Mean Weight
Fertilizer	Mineral	258.8 a
	Biosol	488.4 c
	Biosol + P	371.1 b

Table 21. Analysis of variance for perennial forb production, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	533.48	266.74		
Mulch	4	319.52	79.881	.31	.8643
Residual	8	2068.6	258.57		
Fertilizer	2	10.711	5.3556	.03	.9690
Mulch x Fert	8	1778.8	222.36	1.31	.2941
Residual	20	3394.3	169.71		

Table 22. Analysis of variance and least significant difference for total perennial production, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	16987	8493.7		
Mulch	4	395200	98801	1.32	.3412
Residual	8	598830	74854		
Fertilizer	2	395150	197580	14.23	.0001
Mulch x Fert	8	417630	52204	3.76	.0077
Residual	20	277770	13888		

LSD Analysis

Factor	Identity	Mean Weight
Fertilizer	Mineral	264.3 a
	Biosol	493.8 c
	Biosol + P	375.5 b

Table 23. Analysis of variance and least significant difference for annual grass production, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	67149	33574		
Mulch	4	.13582E+07	339560	10.11	.0032
Residual	8	268600	33574		
Fertilizer	2	103510	51753	0.52	.6048
Mulch x Fert	8	414020	51753	0.52	.8306
Residual	20	.20071E+07	100360		

LSD Analysis

Factor	Identity	Mean Cover
Mulch	WF 1	.00002 a
	WF 2	.00002 a
	Grass	.00002 a
	Straw	434.3 b
	None	.00002 a

Table 24. Analysis of variance for annual forb production, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	61689	31844		
Mulch	4	65641	16410	0.75	.5868
Residual	8	175820	21978		
Fertilizer	2	19297	9648.3	0.64	.5373
Mulch x Fert	8	119340	14918	0.99	0.4719
Residual	20	301060	15053		

Table 25. Analysis of variance for total plant production, 1989 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	339850	169920		
Mulch	4	.16456E+07	411390	1.77	.2279
Residual	8	.18594E+07	232420		
Fertilizer	2	626990	313500	1.46	.2570
Mulch x Fert	8	.11213E+07	140170	.65	.7271
Residual	20	.43086E+07	215430		

Table 26. Analysis of variance and least significant difference for perennial grass production, 1994 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	521770	260880		
Mulch	4	.21207E+07	530180	.38	.8204
Residual	8	.11308E+08	.14135E+07		
Fertilizer	2	.97380E+07	.4869E+07	9.19	.0015
Mulch x Fert	8	.28124E+07	351560	.66	.7168
Residual	20	.10595E+08	529750		

LSD Analysis

Factor	Identity	Mean Weight
Fertilizer	Mineral	1330 a
	Biosol	1001 a
	Biosol + P	2110 b

Table 27. Analysis of variance and least significant difference for perennial forb production, 1994 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	166340	83172		
Mulch	4	358090	89523	1.25	.3629
Residual	8	571470	71433		
Fertilizer	2	688250	344120	8.43	.0022
Mulch x Fert	8	722730	90341	2.21	.0716
Residual	20	816470	40823		

LSD Analysis

Factor	Identity	Mean Weight
Fertilizer	Mineral	528.4 b
	Biosol	230.2 a
	Biosol + P	333.3 a

Table 28. Analysis of variance for annual forb production, 1994 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	447.68	223.84		
Mulch	4	1289.9	322.49	.72	.6037
Residual	8	3599.5	449.94		
Fertilizer	2	116.41	58.206	.23	.7935
Mulch x Fert	8	3036.9	379.62	1.53	.2104
Residual	20	4975.8	248.79		

Table 29. Analysis of variance and least significant difference for total plant production, 1994 (P=0.10).

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	211700	105850		
Mulch	4	.14809E+07	370230	.27	.8922
Residual	8	.11164E+08	.13955E+07		
Fertilizer	2	.11004E+08	.55018E+07	11.1	.0006
Mulch x Fert	8	.35586E+07	444820	.90	.5366
Residual	20	.99098E+07	495490		

LSD Analysis

Factor	Identity	Mean Weight
Fertilizer	Mineral	1866 b
	Biosol	1236 a
	Biosol + P	2447 c

APPENDIX C

1994 Plant Species

Table 30. Plant species observed on test plots, 1994.

Scientific name	Common name
Agropyron dasystachyum	Thickspike wheatgrass
Agropyron spicatum	Bluebunch wheatgrass
Agropyron trachycaulum	Slender wheatgrass
Orzyopsis hymenoides	Indian ricegrass
Calamovilfa longifolia	Prairie sandreed
Festuca ovina	Sheep fescue
Agropyron smithii	Western wheatgrass
Artemesia ludiviciania	Cudleaf sagewort
Grindelia squarrosa	Curly cup gumweed
Poa pratensa	Kentucky bluegrass
Phleum pratense	Timothy
Oxytropis spp.	Oxytropis
Vulpia ochflora	Six weeks fescue
Kolaria cristata	Praire junegrass
Linum lewisii	Blue flax
Meliolitus alba	White sweet clover