Revegetation research on hard rock mining disturbances in north-central Montana
by Michael Jerome Spry

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

Abstract:
Hard rock mining developments in Montana are subject to regulation under the 1972 Montana Metal Mine Reclamation Act. Many mine operators are unfamiliar with revegetation techniques and are unable to develop reclamation plans, as required by the Act. The purpose of this study was to develop revegetation techniques for hard rock mining disturbances near Zortman, Montana. The disturbances included a waste rock dump, abandoned tailings, and a clay pit. Environmental conditions at these sites were characterized using physicochemical analyses of surface materials, soil water monitoring, and water retention analyses. Research plots were established at each site to study seeded and transplanted species. Germination percentage was measured to evaluate establishment of seeded species.

Results of site characterizations indicated low water availability was the main limiting factor at all sites. The effect of low water availability on seedling establishment and growth was evident during the 1984 growing season. Plant performance was poor at the clay pit and tailings site. At the waste rock dump, however, seeded species remained healthy and produced some growth, in spite of severe drought. These results indicate that successful revegetation of the clay pit and abandoned tailings will require enhanced water availability and surface stabilization. Further research is needed on these sites and on the waste rock dump to identify appropriate seed and fertilizer rates, timing, and seeding methods, so that plant establishment is maximized.

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APPROVAL

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Michael Jerome Spry

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

March 24, 1986 — Date

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ABSTRACT

Hard rock mining developments in Montana are subject to regulation under the 1972 Montana Metal Mine Reclamation Act. Many mine operators are unfamiliar with revegetation techniques and are unable to develop reclamation plans, as required by the Act. The purpose of this study was to develop revegetation techniques for hard rock mining disturbances near Zortman, Montana. The disturbances included a waste rock dump, abandoned tailings, and a clay pit. Environmental conditions at these sites were characterized using physicochemical analyses of surface materials, soil water monitoring, and water retention analyses. Research plots were established at each site to study seeded and transplanted species. Germination percentage was measured to evaluate establishment of seeded species.

Results of site characterizations indicated low water availability was the main limiting factor at all sites. The effect of low water availability on seedling establishment and growth was evident during the 1984 growing season. Plant performance was poor at the clay pit and tailings site. At the waste rock dump, however, seeded species remained healthy and produced some growth, in spite of severe drought. These results indicate that successful revegetation of the clay pit and abandoned tailings will require enhanced water availability and surface stabilization. Further research is needed on these sites and on the waste rock dump to identify appropriate seed and fertilizer rates, timing, and seeding methods, so that plant establishment is maximized.

INTRODUCTION

Increases in precious metal prices over the past decade have resulted in new hard rock mining developments throughout Montana. These developments are subject to regulation under the Montana Metal Mine Reclamation Act of 1972, which mandates the reclamation of hard rock disturbances. In order to comply with the provisions of the Act, hard rock mine operators must submit a reclamation plan which defines the proposed post-mine land use and describes the type of vegetation cover to be established.

Because mine operators are often unfamiliar with revegetation methods, they are unable to develop a reclamation program that satisfies the requirements of the Act. This problem has come to the attention of the Montana Department of State Lands (DSL), which administers the Act. In order to ensure that hard rock disturbances are reclaimed to the extent required by the Act, the DSL, in cooperation with mine operators, is sponsoring research on the revegetation of hard rock disturbances. This research will be used to develop recommendations for mine operators who are attempting to reclaim hard rock disturbances throughout Montana.

The purpose of this study was to develop revegetation techniques for disturbances associated with a large open-pit gold and silver mine near the town of Zortman, Montana. Disturbances at this mine include waste rock dumps, leach pads, abandoned tailings, and clay pits. In order to develop revegetation techniques for these disturbances, representative sites were chosen for study. Unfortunately, this study did not include a leach pad site because all leach pads were active when the research was initiated. Therefore, recommendations for leach pad revegetation are not included here.

The objectives of this study were to: (1) characterize environmental conditions at each site, including physical and chemical properties of the root zone materials, (2) identify environmental factors which limit revegetation potential, (3) demonstrate revegetation techniques using trial plots, and (4) develop recommendations for the revegetation of the disturbances, based upon site characterizations and the results of revegetation trials.

LITERATURE REVIEW

Revegetation of Hard Rock Mining Disturbances

Most research on the revegetation of hard rock disturbances has involved alpine environments. Brown and others have intensively studied the revegetation of alpine mine disturbances on the Beartooth Plateau in southern Montana (Brown et al., 1976; Brown and Johnston, 1976, 1978, 1980; Brown et al., 1984). Alpine revegetation research has also been conducted on molybdenum mines in Colorado (Brown, 1974; Guillaume, 1980; Jackson, 1982).

Results of this research indicate that native species are better suited for alpine revegetation than are introduced species. Although introduced species may establish rapidly (Richardson, 1980), native species are adapted to harsh climatic conditions and provide a stable plant community (Brown et al., 1976).

Successful alpine revegetation may require amendment of mine spoils, including the addition of lime, fertilizer, organic matter, or surface mulch (Brown and Johnston, 1978). Liming of acidic spoils reduces heavy metal toxicity and enhances the availability of some nutrients (Johnston et al., 1975). Fertilizer application overcomes inherent nutrient deficiencies and stimulates organic matter production (Richardson, 1980). Direct addition of organic matter, such as manure, improves water holding capacity, aeration, and nutrient availability (Brown et al., 1976). Finally, surface mulches can be used to enhance plant establishment. Mulches improve infiltration, hold seed in place, retain water for plant uptake, and ameliorate surface temperatures (Kay, 1978).

In addition to amendments, coversoil has been considered for use on hard rock spoils. Parady (1981) assessed the suitability of alluvial overburden for use as a coversoil on acidic waste dumps. Use of the alluvium required amendment with organic matter to reduce crusting. Lawson (1984) reported better establishment of three grass species on the alluvium amended with manure than amendment with hay mulch or fertilizer. Both studies were conducted at the Berkeley Pit Complex near Butte, Montana, where alluvial overburden is relatively abundant. Use of coversoil has received little attention elsewhere because suitable topsoil or overburden is scarce near hard rock mines, especially in alpine environments (Brown et al., 1976).

Revegetation of Mill Tailings

Mill tailings are a common disturbance associated with hard rock mining. Revegetation of these materials poses unique problems because of severe environmental conditions. Factors which hinder revegetation efforts include high salinity, heavy metal toxicity, acidification, and nutrient deficiencies (Nielson and Peterson, 1978). Vegetation on tailings also is subject to desiccation and scouring by wind (Deckler, 1982). Water stress which results from desiccation is exacerbated by low available water holding capacity of most tailings. Moreover, plants may be subject to excessive solar radiation because of high reflectivity of tailings surfaces (Dean et al., 1973).

Some of these limiting factors have been addressed in revegetation attempts. Nielson and Peterson (1978), who worked with tailings produced by copper smelting operations, leached the tailings to remove salts. This treatment and fertilizer applications resulted in high establishment and survival rates for *Agropyron elongatum, Medicago sativa,* and *Melilotus officinalis*. Dean et al. (1973) demonstrated two methods for desalinization of copper tailings in Utah. One method involved the stratification of sand and "slime" layers to reduce upward migration of salts. For the second method, mounds of tailings were oriented in an east-west direction to reduce evaporation and upward salt migration on north-facing sides. Both methods reduced salinity; vegetation was healthier and more dense on north-facing slopes and on stratified tailings than on unaltered tailings.

In addition to desalinization, successful tailings reclamation may require surface stabilization to reduce wind erosion, seed loss, and scouring of seedlings (Deckler, 1982). Nielson and Peterson (1978) recommended the use of chemical soil binders or plant residue mulches to reduce wind erosion. Dean et al. (1973) demonstrated the use of asphalt and synthetic polymers to agglomerate tailings particles. Compost and sewage sludge also were used to improve aggregation and reduce erosion. They concluded that revegetation, aided by application of a chemical or organic stabilizer, would assure long-term stabilization of tailings.

Minesoils with High Rock Fragment Content

Rock fragments in mineoils often are considered to inhibit revegetation. Inhibitory characteristics include excessive drainage, instability on steep slopes, and heat injury to vegetation (Down, 1975). However, the presence of rock fragments can benefit revegetation. High rock fragment content concentrates soil water in the <2 mm fraction, which makes water more available for plant uptake. Plants compensate for the reduced amount of soil by extending roots vertically and horizontally around fragments (Ashby et al., 1984).

Rock fragments can be especially beneficial to tree establishment. Successful establishment of *Pinus resinosa* has been reported on Pennsylvania coal mine spoils containing 60 to 80% coarse fragments (Aharrah and Hartman, 1973). Kolar et al. (1981), who studied tree establishment in Illinois mine spoils, reported that growth of deciduous species on coarse spoils was nearly double the growth on topsoiled spoils and on undisturbed silt loam.

Tree establishment on coarse minesoils in the Northern Great Plains is less documented. Stark (1982) investigated establishment of *Pinus ponderosa* on surface-mined lands in southeastern Montana. Stark suggested that *Pinus ponderosa* establishment can be enhanced by constructing minesoils with large rock fragments on the surface. These fragments would simulate natural rocky outcrops where *Pinus ponderosa* thrives.

According to Stark (1982), surface rock fragments enhance water availability to trees by a "distillation-condensation" process. The rocks conduct heat into the soil during the day, which vaporizes soil water. At night, the vapor moves toward the surface where it condenses under cooling rocks. Although this process may enhance tree establishment, successful establishment using surface rock fragments has not been documented in the Northern Great Plains.

Other research in the Northern Great Plains has involved shrub establishment on coarse materials. In 1971, twelve shrub species and two tree species were seeded on scoria fill in southeastern Montana (Hodder and Sindelar, 1972; Dollhopf and Majerus, 1975). After four years, density measurements revealed that only *Atriplex canescens, Sarcobatus vermiculatus,* and *Artemisia nova* survived in moderate to high numbers (DePuit and Dollhopf, 1978). Poor performance of several species native to scoria outcrops could not be explained. DePuit and Dollhopf concluded that interspecific site requirements required further study.

Stabilization and Revegetation of Steep Waste Dumps

Stabilization and revegetation of steep waste dumps are difficult because dump slopes often are characterized by severe erosion and mass instability. Erosion and mass movement occur because traditional dump construction consists of dumping spoils downslope and allowing gravity to sort the materials. Dumping results in stratification of materials, with smaller rock fragments and the <2 mm fraction overlying larger rock fragments. This stratification promotes slippage between disparate fragment sizes and along the base of the dump where water accumulates. Erosion occurs because dump surfaces mainly consist of the <2 mm fraction, which is readily displaced by runoff on steep slopes (Riddle and Saperstein, 1978).

The head-of-hollow or valley fill is an alternative dump construction method which may reduce erosion and instability. This method involves placement of spoil in lifts which are constructed from the bottom of the drainage toward the top. Head-of-hollow fills are more stable than traditional dumps because the lifts are not stratified. The fills also are constructed with drains, which reduce erosion and water accumulation. Thus, by controlling erosion and instability, the head-of-hollow fill method creates a stable environment for revegetation (Ramani and Grim, 1978).

Use of the head-of-hollow fill has been successfully demonstrated at phosphate mines in Idaho (Farmer and Richardson, 1980). These dumps are constructed on steep mountain slopes and graded to conform to the original topography. Grading and shaping enhance surface stability and allow safe operation of reclamation equipment (Farmer and Blue, 1978).

After grading, the phosphate dumps are sometimes covered with topsoil, subsoil, or shale parent materials. The dumps are ripped and harrowed to improve the seedbed. Heavy fertilizer applications are used to promote biomass production which provides soil organic matter (Farmer and Blue, 1978). These procedures have yielded highly productive stands of native and introduced species on the dumps (Farmer and Richardson, 1980).

Effects of Water Stress on Germination and Seedling Growth

Germination

Germination of grass species is inhibited with decreasing matric potential. McGinnies (1960) reported that germination of six grass species was significantly reduced at potentials between -7.5 and -15 bar. Germination of *Agropyron smithii* may be inhibited below -7 bar (Bokhari et al., 1975). Knipe (1973) reported reduced germination of the same species at -1 bar. Germination of some warm season grasses may be reduced at potentials below -0.3 bar (Knipe and Herbel, 1960).

Germination is delayed or inhibited by water stress because seeds are unable to imbibe sufficient water. Imbibition is slowed with decreasing potential. As the soil dries, the potential gradient steepens at the seed-soil interface (Currie, 1973). Eventually, the potential gradient may be too steep to allow imbibition to continue, so that germination is inhibited.

Large seeds may be more susceptible to water stress than small seeds. Large seeds have more surface exposed to the air than in contact with water. As the soil dries, large seeds may evaporate more water than they can take up (Harper and Benton, 1966). In contrast, small seeds have a larger wetted surface to total surface area ratio; they are less affected by drying and may germinate at higher rates in dry soil than do large seeds.

The effect of water stress also may vary with seed position in the soil. Nelson et al. (1970) reported significantly lower germination of six *Agropyron* species on broadcast plots than on drill-seeded plots. Broadcast plots had lower germination because rapid drying reduced soil water content and potential at the surface (Wilson et al., 1970).

Seedling Growth

Water stress slows or suspends growth of grass seedlings. Initial effects of water stress are reduced shoot and root growth because of reduced turgor pressure (Brown, 1977). Eddleman and Nimlos (1972) reported shoot growth cessation in *Agropyron smithii* seedlings when matric potentials reached -30 bar at 4 to 12 cm depth. Root growth ceased at -7.5 bar at the same depth. Leaf growth cessation has also been observed in *Agropyron inerme*; growth cessation in this species may be associated with photosynthetic dormancy (DePuit and Caldwell, 1975).

MATERIALS AND METHODS

Experimental Design and Statistical Analyses

Revegetation research plots were constructed on a waste rock dump, abandoned tailings, and a clay pit. At the waste rock dump, nine blocks were placed in three rows on two adjacent benches. Each block consisted of six 1 m^2 plots for six seeded species. Blocks were not randomized; an order of species was established for each row of three blocks and repeated three times. Plot configurations are depicted in Figure 1.

The same numbers of blocks and plots were used at the tailings site. Blocks at this site were placed close together in an area of uniform tailings depth. Blocks were arranged in three groups; each group consisted of two blocks placed in parallel and a third block placed downslope. An order of species was established and repeated three times in each group of three blocks. Plot configurations are depicted in Figure 2.

At the clay pit, three blocks were constructed at three locations which differed in slope and aspect. Each block consisted of three replicate 1 m^2 plots for each of four species. An order of species was established and repeated three times in each block. Plot configurations are depicted in Figure 3.

The species seeded in the research plots are listed in Table 1. All the species, except *Pinus contorta*, are adapted to semi-arid environments and are commonly used in the reclamation of mine disturbances in the Northern Great Plains. Seeding rates used in this study were based on rates commonly used in mineland reclamation.

All species were broadcast seeded at all sites in late October 1983, except for *Agropyron spicatum*, which was seeded at the waste rock dump in early May and at the tailings