REVEGETATION EXPERIMENTATION ON AN ABANDONED COPPER MINE IN CALIFORNIA [1]

by

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__Abstract.__ Disposal of sulfide-rich mine tailings in combination with rain water and air have resulted in Acid Rock Drainage (ARD) degrading surface and ground water at the abandoned Spenceville Copper Mine in the central California foothills. Lack of a vegetative cover has resulted in eroding slopes and sediment loads contaminating the local drainage of Little Dry Creek. Limiting the movement of reactive waste materials and surface water flow over tailings would greatly reduce contaminates entering the creek. The development of a sustaining, low cost, and low maintenance vegetative cover is an integral part of a comprehensive acid rock drainage abatement strategy for the abandoned mine site because of the ability of the vegetative cover to reduce percolation by evapotranspiration and by reducing surface erosion. In an attempt to reduce the cost of importing topsoil and the environmental degredation that ensues when topsoil is removed, we chose to utilize the substrate onsite for growth media. The research described in this paper describes the first phase in developing reclamation strategies that will produce a self-sustaining vegetative cover able to reduce ARD at the Spenceville Copper Mine.

The tailings and exposed waste materials have little plant available nutrient levels, a low pH, and high heavy metal concentrations. Three categories of barren waste were identified based on geochemical characteristics. Analyses were conducted on the waste material to identify growth limiting factors. To develop a growth media capable of sustaining vegetation, test plots were installed on each type of mine waste and contrasted three different treatments 1) waste lime plus nutrients, 2) biosolids (composted sewer sludge) plus waste lime and nutrients, and 3) nutrients only.

Native and non-native plants were grown in test plots onsite in each of the growth media treatments. Plants in the test plots were monitored for seed germination and survival, plant growth and vigor.

Additional Key Words: Acid Rock Drainage, Abandoned Mine, Biosolids, Revegetation

Introduction

The Spenceville Copper Mine had been worked almost continuously between the 1860s and 1918. In the years that the site was in operation, copper, paint, and sulfuric acid were produced. The depth of the mine proceeded to between 100 and 150 feet with the original tunnel broadened into an open pit excavation. Extracted ore was roasted and copper extracted by leaching. Waste dumps of the original underground mine were reworked by water leaching and precipitation on scrap iron.

The site currently consists of leached ore, roasted ore, low grade ore or waste rock dumps, and the pond which fills the mine pit. The large open pit is surrounded by several acres of tailings which lie in terraces up-slope of the pit. Mining has caused the exposure of copper-rich sulfates and iron pyrite to oxygen and water. The chemical reactions and leaching of the tailings and pyrite rich wall rock in the mine pit has resulted in the generation of acid rock drainage (ARD) in the form of sulfuric acid and the

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release of heavy metals into solution. Once in solution, these heavy metals are released directly into Little Dry Creek and Dry Creek by surface flows during heavy rains and ground water through the bedrock fractures and stream terrace deposit. Previous investigations estimated that total mass discharge of copper to Little Dry Creek is 32 kilograms/year of which 97% is derived from the waste rock piles.

Site Description

The Spenceville Copper Mine is an abandoned mine site located within the California Department of Fish and Game Spenceville Wildlife Management and Recreation Area, 10 miles southeast of Smartville and 17 miles southwest of Grass Valley, California, at an elevation of 450 feet. The site is directly adjacent to Little Dry Creek, just north of its confluence with Dry Creek.

Spenceville Copper Mine encompasses approximately 10 acres within the Foothill Pine-Oak Woodland (Holland, 1986) natural community. The vegetation surrounding this site is dominated by foothill pine (*Pinus sabiniana*) and blue oak (*Quercus douglasii*), with an understory of buckthorn (*Ceanothus cuneatus*), manzanita (*Arctostaphylos visida*), and annual grasses. A narrow riparian zone surrounds Little Dry Creek. The mine pit, waste dumps, and leach rock are devoid of vegetation and are exposed to wind and water erosion.

Annual precipitation in the mine is approximately 34 inches with annual evaporation of approximately 55 inches. Surface water flows into the mine pit from a watershed of approximately 10 acres consisting mostly of the barren waste rock piles. Deep gullies have eroded into the lower portion of the waste pile with sediment discharging primarily into the mine pit.

Soil Chemistry

Four major chemical and mineralogical problems were identified: low pH, phytotoxic levels of metals and metalloids (aluminum, zinc, copper, arsenic), lack of plant available nutrients, and massive, compacted soil structure that prevents adequate water infiltration, drainage, or retention. Ameliorating these soil problems is imperative in creating a sustainable vegetative cover (Haigh, 1992).

Substrate Materials

Three general types of substrate (soil-like) materials were identified on the site. These mining material substrates are identified as hematite tailings, jarosite mine spoil, and three classes of reddish-orange iron-rich terrace substrate. The native soils of the area are mapped as alfisols, which are relatively weathered soils on sedimentary and metasedimentary geological materials.

The hematite tailings are a typical product of roasting complex sulfide ores under sulfating conditions. The texture consists of porous aggregates of very small hematite crystals with impregnation of poorly crystallized jarosite. The mineralogy of the hematite consists almost entirely of hematite, jarosite, quartz, and the barium sulfate mineral barite. Hematite strongly adsorbs both metals and anions such as sulfate and phosphate, and has a strong effect on the plant availability of these components.

The jarosite mine spoil consists largely of the secondary iron sulfate mineral jarosite, with some quartz, and the calcium sulfate mineral gypsum. Jarosite is stable only at pH less than 5, at higher pH it breaks down to form iron oxyhydroxide minerals, sulfate salts, and gypsum. The jarosite spoils contain the largest quantity of sulfides.

The reddish-orange terrace substrate is an intermediate in composition between the jarosite mine spoil and hematite tailings, and is basically a mixture of waste rock, jarosite mine spoil, and hematite tailings. Based on the initial soil chemistry data, we expected that the native soils and reddish-orange terrace substrate would out perform the jarosite mine spoil and hematite tailings, and we expected the jarosite and hematite to be equally inhospitable to plant materials.

Soil Buffering

The hematite tailings material showed greatest initial buffering at about pH 4.5. The largest overall buffering by mine waste material was exhibited by the jarosite mine spoil, which showed strong buffering the pH range of 3.5 to 4.5. The reddish-orange terrace substrate showed greatest buffering from pH 3.5 to 4.0. By contrast, native soil collected from west of the mine site shows no consistent buffering trends at pH levels related to jarosite or iron containing minerals.

Plant Nutrients

Since plant available nutrient requirements for most wildland species are not known, laboratory growth experiments were conducted using a fast growing non-native zorro fescue (*Vulpia myuros*). These growth data indicated that none of the mined materials had sufficient nutrients for plant growth without the addition of amendments. Nitrogen, phosphorous, and potassium were deficient for all mined materials, except for the jarosite spoil which had significant amounts of potassium. Calcium (Ca) and magnesium (Mg) were low, but since waste lime was used to ameliorate the low pH, the inherent Ca and Mg contents are irrelevant. Sodium was low and sulfate was very high. Micronutrients and metal phytoavailablity are hard to predict, but generally, metal toxicity was not expected except possibly with copper in reddish-orange terrace substrate.

Organic matter in the mined materials was low, measuring 3 or 4 g kg^{-1}, with native soils containing 28 g kg^{-1}. Low levels of carbon in mined material bring about a number of other problems relating to plant growth including: poor water holding capacity, poor nutrient retention capacity, low microbial activity, low aggregate stability, high susceptibility of nutrient adsorption onto the bare metal surfaces, and high availability of any heavy metals.

Methods

Test plots were established on representative sites for the three tailing types: jarosite, hematite, and "orange". On each material type, the treatments (control, lime, lime plus biosolids) were randomly allocated. All treatments received a full compliment of nutrients in addition to any soil treatments. Each treatment was replicated four times within each soil type. The treatments were tested on an annual seed mix consisting of zorro fescue (*Vulpia myuros*) and a locally collected clover (*Trifolium* sp.) and on foothill pine (*Pinus sabiniana*), with four seedlings per replicate. Pine seedlings were watered twice a month unless rain was received. Seedling germination and survival was monitored beginning in April 1994 and was terminated in June 1994. Growth (in cm) and vigor (0=dead, 1=alive, 2=thriving) of the pines were monitored monthly beginning in April 1994 until August 1994. Data were analyzed using an ANOVA within each soil type and a Multifactor ANOVA among all soil types.

Results

Pines

The data for the pine growth is depicted in Figure 1. Data were analyzed within each soil type and among the soil types. There was a significant difference in growth among the soil types and among the treatments at $p=0.06$ and $p=0.02$, respectively, and a significant difference in vigor among soil types and treatments at $p=0.001$.

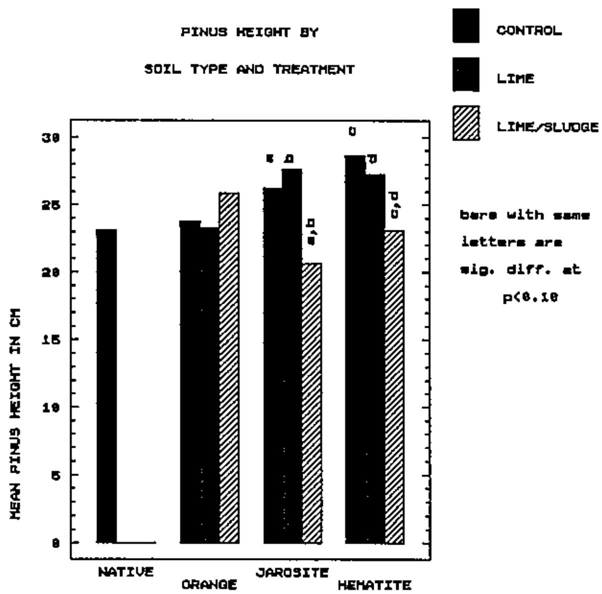

FIG. 1

Growth on the hematite tailings (mean=26.4, n=40) was significantly greater than growth on both the native soil (mean=22.0, n=6) and on the reddish-orange terrace substrate (mean=23.7, n=40). When the data are analyzed within each soil type, the results were as follows: the lime/sludge treatment had less growth on both the jarosite mine spoils ($p=0.001$) and the hematite tailings ($p=0.02$) than the control or lime treatment; and on the reddish-orange terrace substrate, there was no significant difference among soil treatments.

Vigor (inversely related to mortality) was significantly different among all treatments as depicted in Figure 2 at $p=0.11$, with lime out performing both the control and the lime/sludge. Vigor was significantly different among all soils except the reddish-orange terrace substrate and hematite tailings. These soils out performed both the native soil and the jarosite mine spoil at $p=0.10$ (Figure 3).

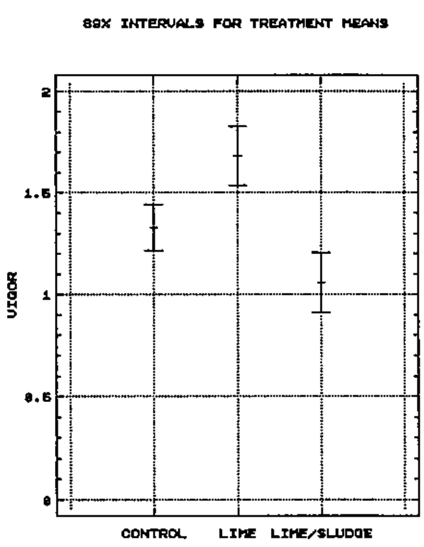

FIG. 2

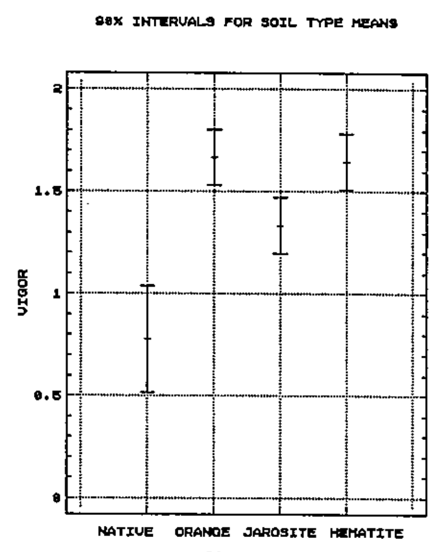

FIG. 3

Seeds

Seed germination was significantly different among soil types ($p=0.002$) and among soil treatments ($p=0.001$). As depicted in Figure 4, germination in reddish-orange terrace substrate was significantly greater than germination in jarosite mine spoils and hematite tailings. And as shown in Figure 5, germination in the lime/sludge treatment was significantly less than germination in either the control or lime treatment.

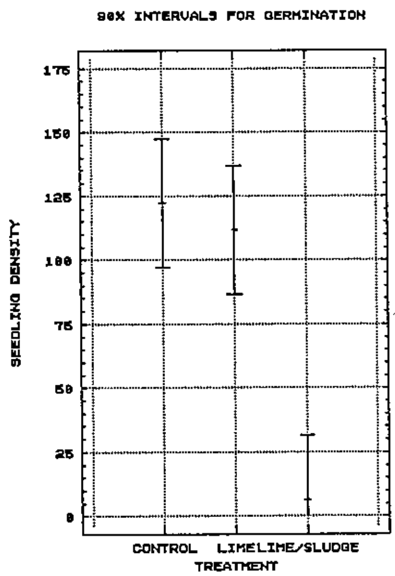

FIG. 5

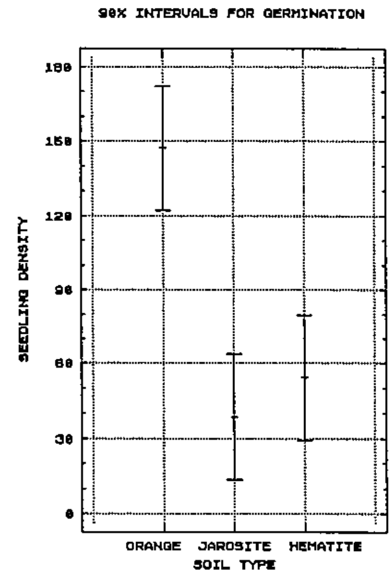

FIG. 4

Seed survival was significantly different among soil types ($p=0.04$) and among soil treatments ($p=0.08$). Survival was significantly greater on reddish-orange terrace substrate than on jarosite mine spoils or hematite tailings, as depicted in Figure 6, and survival was greater on the lime treatments than on either lime/sludge or control as depicted in Figure 7.

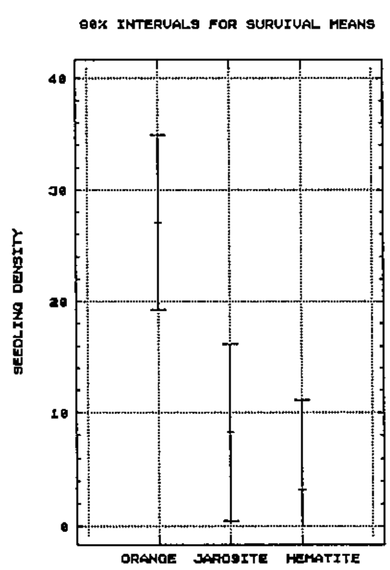

FIG. 6

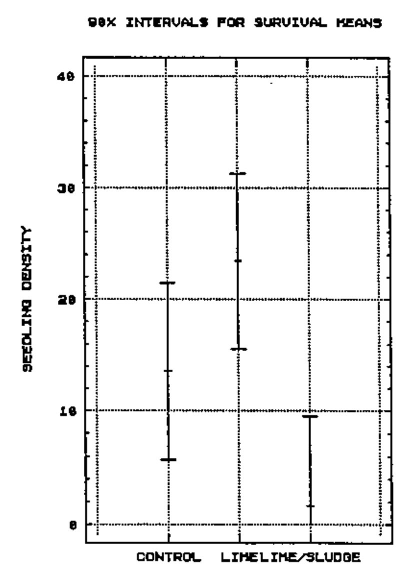

FIG. 7

Figure 8 shows the seed survival data for each treatment and soil type, with the only significant difference within a soil type is found between lime and lime/sludge on the reddish- orange terrace substrate.

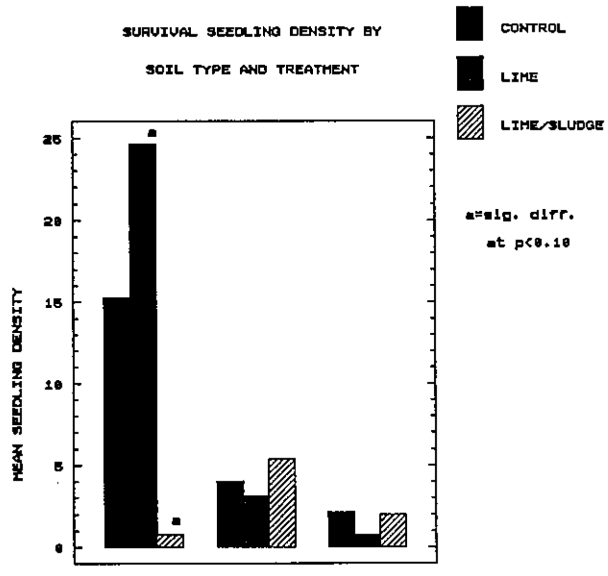

FIG. 8

Discussion

Based on our first year of pine data, what was believed to be the one of the most inhospitable substrates, hematite tailings, out performed the native control site and the less toxic reddish-orange terrace substrate site. In addition, on the pines, the lime treatment did not out perform the control treatment, while the lime/sludge treatment appeared to have a detrimental effect.

The data for seed germination indicate that the reddish-orange terrace substrate was the best substrate, that the lime treatment was not different from the control treatment and that the lime/sludge treatment had a detrimental effect. The lime treatment resulted in more seedlings than the control treatment only in the survival data on the reddish-orange terrace substrate.

Therefore, it would appear that lime is necessary for survival of seeds, but not for growth of pines, and that the lime/sludge treatment was detrimental to plant germination, growth, and survival.

We speculate that the potting mix for the pine seedlings may have had enough residual phosphorus to produce an advantage for the root growth. We further speculate that the particle size of the sludge (composted biosolids) was too large and actually wicked water away from the plants and seeds causing drought stress. Waste lime, while beneficial for ameliorating the low pHs of the site increase the electrical conductivity (salinity) of the soils causing salt stress. The poor results on the native control plot may be due to competition with annual species and compaction of substrate.

Current Research

To further refine the strategy for establishing a sustaining vegetative cover, we have implemented the second phase of research. In October 1994, we installed additional test plots to examine the following parameters.

1) Site-specific native species were planted to ascertain their survivorship.

2) The plots have been throughly watered to leach the salts added by the waste lime.

3) Because biosolids are an attractive organic amendment both economically and environmentally, we chose to retest the biosolids in a finer form that can be incorporated more throughly into the test substrates and not interfere with water availability for the plants or seeds.

4) Plants were planted during the correct season for successful establishment in central California.

Data will be collected monthly and this information will be used to finalize the revegetation plan for the Spenceville Copper Mine.

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