Sewage Sludge as an Organic Amendment for Reclaiming Surface Mine Wastes

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Introduction

Surface mining for minerals is unavoidably an environmentally destructive process. The properties of mined soils make them a poor medium for plant growth and natural recolonization on these soils is slow (Sengupta 1993). Unvegetated mine spoils are devoid of vegetation and prone to erosion, resulting in further environmental degradation (Tennessee Valley Authority 1963). Reclaiming these highly disturbed soils is an important process in returning land to a stable state. This paper will discuss the problems associated with mine soils and the use of sewage sludge as a reclamation tool.

Background

In the United States, common minerals that are surface mined are coal, kaolinite, bentonite, zinc, uranium, and copper. There are two types of surface mining: strip mining and open pit. Open pits are typically used for mining metals while strip mining is the method for removing coal and clays. Strip mining is a three phase process. The first phase is the removal of the overburden (vegetation, soil, and bedrock) and mining of the desired mineral. Phase two involves filling stripped areas with the overburden of the current active site. Lastly, the filled area is graded and vegetated. Open pit mining does not have a phase-series like strip mining. Instead, the overburden is stockpiled. At the end of operation, the pit size determines reclamation. Large pits are left open and the overburden is graded in place then vegetated. Smaller pits are backfilled with overburden and reclaimed (Rieth 1986).

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) requires that a mined site is restored to a condition of similar topography and equal or greater vegetative production (Wells and Potter 1986, Roberts et al. 1988a). Because mine soils are highly susceptible to erosion, rapid establishment of vegetation aids in stabilizing the soils and is a step towards meeting the requirements of SMCRA. In order to begin mining, a company is bonded by the government. A bond requires a substantial cash deposit from the company. In order for the bond to be released, the conditions set forth by SMCRA must be met. Release from a bond is another reason rapid reclamation is desired.

Mine Soils

Mine soils have a multitude of problems. One goal of mine soil reclamation is control of pH and leaching. Removal and crushing of bedrock exposes geologic material that is not stable at earth surface conditions. Alterations of this material can impact the chemistry of the environment. For example, pyrite (FeS₂), a reduced form of iron common in bedrock, oxidizes to sulfuric acid (H₂SO₄) and iron oxide (Fe(OH)₃) when exposed at the earth’s surface (Bohn et al. 1985). Leaching of H₂SO₄ from mine soils, called acid mine drainage, is one source of surface and groundwater contamination. The lowered pH of mine soils also increases the solubility of toxic metals such as aluminum and manganese and allow leaching of essential nutrients.
The physical and chemical characteristics of mine soils affect the success of reclamation efforts. Characteristics of mine soils vary depending on the quality of the original soil, the amount and size of pulverized bedrock included in the spoil, and the method of placement. Roberts et al. (1988a) summarized the characteristics of newly reclaimed mine soils in the coal mining region of the Appalachian Mountains. When compared to native soils, new mine soils have large quantities of coarse fragments, lower cation exchange capacity (CEC), decreased organic matter content, lowered nutrient status, poor water holding capacity, low pH, and increased Fe oxides. Coarse fragments result in large void spaces within the soil matrix. Such spaces transport water rapidly and decrease the ability of the soil to hold water for plant growth. Soil structure, essential for good plant rooting, is absent in new mine soils. Low CEC and nutrient status result in increased need of nutrient management of the soils to ensure plant growth. Lowered pH may make toxic metals available for plant uptake. Thompson et al. (1987) measured the bulk densities ($\rho_b$) and soil strength (resistance to penetration) for three mine sites in Southern Illinois. They found that while $\rho_b$ of mine spoils varies with application method, be it bulldozer or spreading, there is an overall increase in these soil properties with respect to natural soils. Dense soils with high soil strength are difficult for plant roots to penetrate.

Topsoil is an important aspect in mine spoil reclamation. The topsoil is the upper portion of undisturbed soil and contains the building blocks for plant growth: organic matter, phosphorus, nitrogen, and biota such as fungi and bacteria. Disruption of this soil zone by mining impacts the quality of the soil. Mine soils have lower rates of decomposition, decreased nitrification, and reduced enzyme activity (Lindeman et al. 1984). These disruptions decrease the productivity of the soil. Organic matter is the food source for soil microbes and serves as a slow-release nutrient source for plants. Slowed decomposition hinders the release of essential nutrients and also results in a nutrient sink. Nitrification, the conversion of NH$_4^+$ (ammonium) to NO$_3^-$ (nitrate), is important because plants often uptake NO$_3^-$ preferentially to NH$_4^+$ (Tisdale et al. 1985).

Stockpiling topsoil to reserve it for future topdressing to mine soils is often done at mine sites. However, long term stockpiling results in decreased organic matter content due to oxidation reactions by soil microbes (Wells and Potter 1986, Sengupta 1993). Harris et al. (1989) studied microbial activity and physical properties of topsoil stockpiles ranging from 3 to 252 months in age. They found that older stockpiles have poor structure, high $\rho_b$, decreased microbial biomass, lowered soil nitrogen, and decreased organic carbon. An anaerobic zone develops rapidly in stockpiled soil and is partially responsible for a decrease in viable mycorrhizal spores (Harris et al. 1989). These problems combine to disrupt soil ecology when topsoil is re-spread, resulting in slowed reclamation.

Occasionally, the soil removed prior to mining is not suitable for reclamation due to pH, toxic elements, CEC, and nutrient capacity (Lindeman et al. 1984, Sengupta 1993). When native soils from the site are inadequate or the topsoil is in poor condition or not stockpiled, amendments to the mine soils are needed to increase productivity. There are many amendments used on mine soils to aid reclamation, including fertilizers, mulches, and fly ash. Sewage sludge has been used as an organic amendment for soils since the Roman Empire (Clapp et al. 1994). The following section will discuss the use of sewage sludge in reclamation of mine lands.
Sewage Sludge in Mine Soil Reclamation

Sewage sludge is a residual product from the treatment of municipal wastewater (Linden et al. 1995). Due to seasonal fluctuations and variation wastewater sources, the characteristics of sewage sludge vary both in locale and time. For example, wastes from Minneapolis have a higher contribution from industry than do wastes from a rural community. Therefore, Minneapolis wastes may have higher concentrations of metals. Over the last twenty years, sewage treatment technology significantly improved the ability to remove toxins and contaminants so that sewage sludge recovered from wastewater treatment plants is relatively ‘clean.’ Linden et al. (1995) summarized the statistics for sewage sludge use in the United States. Sludge production amounts to ~ 27 kg person\(^{-1}\) yr\(^{-1}\). In 1989, land application of sludge, which includes application to agricultural and reclamation sites, was about 33% of the total sludge production. Land application in 1972 was only 20%. Alternative disposal methods are landfilling and incineration. Costs to landfill sludge are increasing as landfill space becomes more limited. Land application is becoming a more viable and affordable alternative.

Sewage sludge contains essential plant nutrients, primarily nitrogen and phosphorus. Typical content is 1-6% total N and 0.1-2% P. Depending on treatment method, sludge also contains ~30% organic matter. The organic matter in sludge is a key component to its success as an organic amendment. Other trace nutrients are potassium, calcium, magnesium, sulfur, and sodium, boron, manganese, copper, molybdenum, and zinc (Linden et al. 1995). Sewage sludge is a convenient amendment because it has many fertilizer constituents in one application.

Problems associated with sewage sludge are the presence of trace elements, toxic organics, and pathogens, such as bacteria and viruses (Linden et al. 1995). Pre-treatments at wastewater plants can often minimize these contaminants. Trace elements of concern are those not essential for plant growth, including cadmium, chromium, mercury, nickel, and lead. Some trace elements (lead and mercury) are highly insoluble or are adsorbed to organic matter or plant roots and become unavailable (Chaney 1990). Except for plants that actively uptake metals, accumulations in plants are unlikely. The other elements can be accumulated in plant tissue. However, current regulations prohibit cumulative applications of sludge that would lead to toxic concentrations of these elements in the soil (USEPA 1993). Most toxic organics are unavailable to plants after application. Pathogen survival after application is also an issue (Linden et al. 1995). Common survival ranges between 2 days and 2 years, depending on the pathogen. Treatments of sludge before application are effective at controlling pathogen survival, ~90% reduction of pathogenic bacteria is common after primary treatment (Angle 1994). Current treatments to control pathogens in sludge are anaerobic digestion, which eliminates aerobic organisms, lime digestion, which increases the pH and destroys pH sensitive pathogens, and pasteurization, which uses either heat or ultra violet radiation to kill microorganisms and destroy viruses. The most resistant pathogens are viruses and studies continue on how to best deal with such pathogens.

Several researchers have studied the effectiveness of sludge for reclamation practices. Experiments have compared crop performance, soil microorganism viability and propagation, and effective loading rates of sludge amended soils with other treatments.. Lindeman et al. (1984) studied the effects of various soil treatments on the number and activity of soil microorganisms in New Mexico mine soils. Treatments included control, topsoiling to 30 cm
depth, incorporation of bottom ash (residual from coal-fired power plants), hay, sewage sludge, and a soil/bottom ash mix. Results of the study showed microorganism growth was stimulated most by organic amendments. In addition, the sewage sludge treatment provided the greatest increase in CEC and highest total nitrogen content.

Roberts et al. (1988b) examined several reclamation options for coal mine soils in Virginia. This highly controlled experiment compared sewage sludge plots with plots amended with sawdust and topsoil (these two treatments also received chemical fertilizer). Sewage sludge was applied at four rates, 22, 56, 112, and 224 Mg ha\(^{-1}\). Soil properties examined were soil development (gauged by depth and structure of the A horizon), water retention, soil pH, CEC, organic matter, nitrogen, available phosphorus, extractable cations, and biomass production of planted tall fescue (*Festuca arundinacea*). High development of the A horizon indicates good plant rooting, an accumulation of organic carbon, and high microbial activity. The other soil properties measured indicate the degree of resemblance to intact soils (a goal of a mine soil reclamation). The results showed that horizon development was greatest in the sludge amended soil, with depths of 11 to 14 cm after 3 yr, compared to 4 cm for the control plots and 6-7 cm for the topsoil and sawdust plots. Sludge plots also had higher rates of nitrogen accumulation. Carbon accumulations were similar for the topsoil, sawdust and sludge amendments. Fescue biomass was consistently higher on the sludge amended sites for all three years (except for the lowest application rate). Increasing the loading rate from 112 to 224 Mg ha\(^{-1}\) did not produce a significant change in fescue biomass. Using the above soil properties as indicators of successful reclamation practices, sewage sludge shows the highest potential as a soil amendment.

Much of the information about sewage sludge as an organic amendment comes from research in agriculture. A study of sludge application to agricultural land in Minnesota has been ongoing since 1971 (Larson et al, 1994; Linden et al. 1995). This study has some important conclusions that can be applied to sludge amendment of mine soils. Crop yields were slightly higher on sludge amended sites than on conventionally-fertilized control sites. This study also shows that cover crop is an important consideration when developing reclamation plans using sewage sludge or other amendments. Grasses, such as reed canary grass (*Phalaris arundinacea* L.), proved more efficient at removing nutrients than some other forages. However, if restoration of native vegetation is a long-term goal of the project, such competitive species need to be avoided. One potential post-mining use of reclaimed land is often pasture, making accumulation of metals in plants and uptake by grazing animals a concern. The Minnesota study showed that negligible amounts of trace metals were taken up by crops grown on sludge amended soils. Therefore, grazing of sludge amended sites will not result in accumulation of metals in foraging animals. During the 25 year study, carbon and nitrogen accumulated in the treated soil and extractable phosphorus was increased. This factor is important for nutrient deficient mine soils. Sludge treated soils maintained an optimal pH throughout the experiment while control plots required liming. A stable pH on mine soils will control acid production and solubility of toxic metals.

**Conclusions**

The properties of mine soils prior to reclamation (low pH, low nutrient and organic carbon, poor stability) make them limiting to ecosystem recovery. If reclamation is slow, these soils can rapidly degrade the remaining ecosystem through erosion and acid mine drainage generation.
The overall goal of reclamation of mine soils is to establish permanent stability and restore the landscape so that it again acts as a functioning portion of the greater ecosystem (Sengupta 1993). Successful reclamation methods will return the disturbed soils to a productive state. The above studies have an important conclusion: sludge amendment increases overall productivity of mine soils when compared to other treatments. Use of sewage sludge has another benefit: there are few negative impacts on the environment when it is used. Sewage sludge as an organic amendment is one effective method for reclamation of mine soils.

References


