The use of composted municipal waste to revegetate a high elevation mine site
by Gary Lynn Vodehnal

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

Abstract:
Mining in alpine and subalpine areas frequently results in surface soil coverings of spoil and overburden that differ substantially from pre-mining soils. These severely disturbed sites frequently require amendments to accelerate the development of desirable nutrient cycles and provide a hospitable growing medium for plants. Composted municipal wastes are becoming more available as greater emphasis is placed on waste reduction at the community level. A market for these waste-generated compost products may be found in the reclamation of disturbed areas. This project evaluated the effects of two types of composted municipal waste and a commercial nitrogen fertilizer on plant establishment, cover, and production. The study site is located at a heap leach gold mine at an elevation of 2,300 meters, 25 kilometers southwest of Helena, Montana. Thirty three plots were established to measure seedling density, vegetative cover, and plant production over two growing seasons. Plots treated with the higher, incorporated rates of EKO sludge compost and Bozeman municipal yard waste compost produced significantly greater plant density, cover, and biomass than the commercial nitrogen fertilizer and unamended top soil treatment. Compost incorporated into the surface horizon produced greater plant cover and biomass than surface applications. After two growing seasons total grass cover and production were significantly greater than all other treatments with the higher rate of incorporated EKO compost. Forb cover and production were significantly greater than all other treatments with the higher rate of incorporated Bozeman compost. Results from this field study suggest that composted municipal wastes enhance the establishment and growth of herbaceous cover on this disturbed high elevation site.

THE USE OF COMPOSTED MUNICIPAL WASTE TO REVEGETATE A HIGH ELEVATION MINE SITE

by

Gary Lynn Vodehnal

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APPROVAL

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Gary Lynn Vodehnal

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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ABSTRACT

Mining in alpine and subalpine areas frequently results in surface soil coverings of spoil and overburden that differ substantially from pre-mining soils. These severely disturbed sites frequently require amendments to accelerate the development of desirable nutrient cycles and provide a hospitable growing medium for plants. Composted municipal wastes are becoming more available as greater emphasis is placed on waste reduction at the community level. A market for these waste-generated compost products may be found in the reclamation of disturbed areas. This project evaluated the effects of two types of composted municipal waste and a commercial nitrogen fertilizer on plant establishment, cover, and production. The study site is located at a heap leach gold mine at an elevation of 2,300 meters, 25 kilometers southwest of Helena, Montana. Thirty three plots were established to measure seedling density, vegetative cover, and plant production over two growing seasons. Plots treated with the higher, incorporated rates of EKO sludge compost and Bozeman municipal yard waste compost produced significantly greater plant density, cover, and biomass than the commercial nitrogen fertilizer and unamended top soil treatment. Compost incorporated into the surface horizon produced greater plant cover and biomass than surface applications. After two growing seasons total grass cover and production were significantly greater than all other treatments with the higher rate of incorporated EKO compost. Forb cover and production were significantly greater than all other treatments with the higher rate of incorporated Bozeman compost. Results from this field study suggest that composted municipal wastes enhance the establishment and growth of herbaceous cover on this disturbed high elevation site.

INTRODUCTION

Hard-rock mining in alpine and subalpine areas frequently leaves spoil materials and overburden on the soil surface. These materials differ substantially from pre-mining soils. Removal of developed surface horizons generally results in spoil material at the surface that is both low in organic matter and high in bulk density (Chambers et al. 1987). Numerous studies have demonstrated that amending soils with organic materials, such as sewage sludge and municipal waste compost, increases soil organic matter content and improves soil structure and long-term fertility (Khaleel et al. 1981; Joost et al. 1987; Seaker and Sopper 1988). These municipal wastes have been successful as organic amendments in minespoil and Superfund site reclamation at low elevations in the eastern United States (Plass 1982; Skousen 1988; Garvey and Donovan 1992).

Composted municipal wastes have not been thoroughly tested in arid regions or high elevation environments of the Western United States (Chambers et al. 1988; Fresquez et al. 1990; Brandt and Hendrickson 1991). Researchers studying revegetation techniques at molybdenum mines above timberline in Colorado found the most economical and beneficial soil amendments to achieve sustainable vegetative cover were applications of sewage sludge mixed with wood chips (Brown 1976). Although applying sludge and wood wastes at high elevations has been successful in revegetating mine spoils, nitrogen levels must be carefully balanced to prevent soil microbes from competing with plants for nitrogen during the decomposition process. Composting the sewage sludge and wood wastes at lower elevations could speed decomposition and eliminate some fluctuation in nitrogen cycling (Norland et al. 1991).

The growth and development of municipal composting facilities has expanded rapidly in recent years as communities across the country search for ways to reduce solid waste and increase the life of dwindling landfill space. Commercial composting operations have proven to be a cost effective and environmentally sound recycling technology (Goldstein and Steuteville 1992; Steuteville 1992).

The purpose of this study was to evaluate the effects of two types of municipal compost and a commercial nitrogen fertilizer on vegetation establishment and production at a high-elevation site disturbed by mining.

LITERATURE REVIEW

High-Elevation Ecosystems

High-elevation ecosystems in the United States occur in mountainous terrain of the eleven western states, a small portion of the northeastern states, and Alaska. These high-elevation systems are found near or above tree-line and are characterized by short, cool growing seasons and long, cold winters. Tree-line varies in the western United States from 3,500 m in the Southwest to about 2,000 m in northern Montana (Brown et al. 1978).

Disturbance To The System

High elevation ecosystems are under increasing pressure from activities such as mineral exploration, mining, grazing, recreation, timber harvesting, road construction, and water development. Of the approximately three million hectares (7.4 million acres) of alpine area in the western United States, almost twelve percent has been disturbed and requires rehabilitation (Brown et al. 1978). Because of past abuse and increased development, a major challenge is to develop the technology and skills necessary to return these ecosystems to a natural, self-sustaining state.

Environmental Considerations In Revegetation of High Elevation Sites

Rehabilitation of disturbed high elevation sites is extremely difficult due to severe climatic conditions. Short growing seasons, low temperatures, strong winds, frost action, precipitation extremes, fluctuating soil moisture conditions, and intense solar radiation are a few of the imposing barriers to traditional rehabilitation efforts in these sites. Reclamation efforts are further complicated by extremes in topography and poor accessibility.

The predominant feature of high-elevation environments is the low heat budget that results from short growing seasons (60 to 90 days) and low growing season temperatures (Brown et al. 1978, Guillaume 1984). Temperatures often fall below 0° C and frost may occur periodically during the growing season (Marr and Willard 1970; Brown et al. 1978). Needle ice and frost action injure plants by lifting young seedlings from the soil and exposing roots to desiccation (Brink et al. 1967). The low heat budget requires special adaptations by plants living in the alpine zone (Billings 1974).

Precipitation occurs mainly as snow during the months of September to June. Total effective annual precipitation can be highly variable for different alpine sites due to uneven distribution. Snow drift patterns result from interactions of wind and topography, with lee slopes and depressions receiving higher snow accumulation than windswept ridges.

Strong wind, a characteristic of high-altitude ecosystems, results in severe desiccation of exposed plant parts during both winter and summer (Johnson et al. 1975). Plants on these sites are subject to increased frost damage and severe abrasion by windblown ice and soil particles. Wind also erodes fine soil particles from disturbed sites, reducing water and nutrient-holding capacities (Brown et al. 1978).

High solar radiation flux densities and increased levels of ultraviolet radiation affect the growth and development of higher plants (Caldwell 1968). High radiation levels result in increased soil and plant surface temperatures, which promote high evaporation and drought during the growing season.

Soil Genesis

Many factors influence the development of soils in high-elevation environments. These include parent material, landform and geomorphic processes, as well as vegetation, biological activity, and climate (Brown et al. 1978). The rate of soil development is limited by slow mechanical weathering of the hard and resistant rock types in these regions. Cold temperatures inhibit chemical reactions and biotic activity that contribute to soil genesis. The resulting soils are young, heterogeneous, and weakly developed (Retzer 1974). This heterogeneity of soils complicates rehabilitation efforts, often requiring site specific reclamation solutions.

Well-drained soils are more extensive than poorly drained soils in alpine regions and possess unique characteristics important to successful revegetation efforts. These soils are generally coarse textured with low organic matter content. Severe drought conditions may exist in high-elevation areas because of the reduced water-holding capacities of soils, coupled with periods of low summer rainfall. These soil-water conditions may inhibit plant establishment and growth (Brown et al. 1978).

Severe Soil Disturbance

Mining in high-elevation areas produces spoil materials and overburden which differ from premining soils. Removal of the weakly developed surface soil horizons results in overburden material that is both low in organic matter and high in bulk density (Chambers et al. 1987). Severe disturbance also affects soil structure, organic carbon and nutrient pools, nutrient cycling processes, and moisture holding capacity (Bradshaw and Chadwick 1980; Marrs and Bradshaw 1982; Brandt and Hendrickson 1991).

One of the most severe soil and water problems in high-elevation areas results from the exposure, through disturbance, of pyrites and other sulfide minerals. Natural oxidation of the exposed sulfide minerals with air and water can result in the formation of acid rock drainage. Under these conditions the surface soils, surface water, and groundwater may become very acidic. Acidity may increase the solubility of certain elements, particularly aluminum, to toxic levels. Runoff of these contaminated waters is detrimental to plant communities and seriously degrades water quality and aquatic ecosystems (Brown et al. 1978).

Topsoil Salvage

Salvaging topsoil prior to disturbance is a desirable reclamation activity. Replacing topsoil accelerates soil development by providing a particle size distribution which helps supply adequate water for plant growth, reduces runoff, introduces a variety of plant and microorganism propagules, and encourages faster establishment of nutrient cycles (Schuman and Power 1981). Unfortunately, topsoil is rarely available in sufficient quantities in a high-elevation environment to be effective in the revegetation process (Brown et al. 1978).

Topsoil salvage on high-elevation sites can cause mixing of the shallow A horizon which contains the bulk of the soil's organic carbon and microorganisms with deeper mineral soils. Consequently these disturbances produce cover soil material that lacks structure and is prone to formation of surface crusts after a few periods of rainfall.

Topsoil can be salvaged from adjacent land to replace soil removed during site disturbance. This practice, however, degrades additional areas, is often very costly, and can result in the introduction of plant species potentially detrimental to revegetation. In addition, when topsoil is stored for only a few months before use many essential microbiological constituents are lost (Miller 1984).

Severe soil disturbances produce conditions in which decomposition and nutrient cycling are drastically reduced (Reeder and Sabey 1987; Schuman and Belden 1991). Severely disturbed areas frequently require amendments to increase nutrient availability and develop sustainable nutrient cycles. Nutrient availability is one of the most important factors in revegetation of high-elevation soils. Plant-available-nitrogen is generally deficient in undisturbed alpine soils in comparison to lower-elevation soil systems. This deficiency is the result of cool summer temperatures and restricted microorganism activity in surface soils (Guillaume 1984). Nitrogen supply to plants depends heavily on microbial decomposition and efficient cycling, since nearly all the nitrogen a plant obtains from the soil is derived from organic matter.

Nitrogen Rate

Nitrogen is required in relatively large amounts by plants and is an essential element for plant metabolism. Impaired nitrogen supply is the most important factor limiting ecosystem development and the attainment of self-sustaining vegetation. In soils, most of the total available nitrogen

(>95%) exists as organic nitrogen (Marrs and Bradshaw 1982) with low levels (<1%) in the form of nitrate or ammonia nitrogen (Faust and Nimlos 1968). In colder climates of high-elevation areas, decomposition rates are very slow. Consequently, there must be a large nitrogen reservoir to provide a sufficient supply through mineralization to meet annual vegetation requirements. The total nitrogen reserve and rate of mineralization are critical to sustained plant growth in disturbed high-elevation systems.

Legumes add significant levels of nitrogen to geologic materials through nitrogen fixation. They help reestablish pathways for rapid nitrogen cycling (Reeder 1990). Several problems are posed by including agronomic legume species (i.e., Trifolium spp.) in a reclamation seed mix for high-elevation sites. High levels of calcium and phosphorus must be added to disturbed soils to maintain a productive legume population (Marrs and Bradshaw 1982). The use of introduced legume species may not be permitted if state reclamation laws require the use of native species. Legumes are also sensitive to some heavy-metal toxicities, phosphorus availability, and competition from many grass species (Plass 1982).

Inorganic Fertilizers

A deficiency of plant-available nitrogen can limit plant growth and long-term stability of land disturbed by surface mining. Deficiencies arise because disturbance drastically alters the flow of nitrogen through the soil-plant-microbial ecosystem. The availability of nutrients, especially nitrogen, depends on the severity of the disturbance (Tilman 1982). A major reclamation goal has been to achieve stabilization of the disturbed site with a desirable plant community that requires little or no long-term fertilization inputs. Hopefully, the community will maintain a level of productivity comparable to that existing before disturbance (Woodmansee et al. 1978). Development of a self-sustaining nitrogen cycle involves both accumulation of nitrogen within the system and efficient cycling of this nitrogen reserve (Marrs and Bradshaw 1982). A minimum nitrogen supply of 1000 kg/ha to develop a self-sustaining nitrogen cycle was recommended by these authors for China clay waste. Some disturbed land may require decades or centuries to accumulate this much nitrogen naturally and evolve toward a stable nutrient cycle (Reeder 1985).

Conventional rehabilitation methods at high elevation sites rely on the use of commercial nitrogen, phosphorous, and potassium fertilizers to increase available nutrients for plant growth and survival (Brown et al. 1978). With low levels of available nitrogen in high-elevation topsoil, a rapid response would be expected from application of small amounts of nitrogen fertilizer. This has not been the case, however. In a study carried out at a high-elevation site in Colorado, 270 kg of NH_4NO_3 (ammonium nitrate)/ha were required before a plant response was noted (Faust and Nimlos 1968). Scott and Billings (1964) reported similar results in the Medicine Bow Range of Wyoming. Application rates of up to 111 kg of nitrogen (equivalent)/ha in bulk fertilizer were absolutely essential for successful and rapid establishment of plants on high-alpine sites (Brown et. al. 1978). However, Brown et al.(1984) found that inorganic fertilizers were not reliable sources of nutrients for plant growth in a high-alpine area unless applied repeatedly over long time periods. Berg and Barrau (1978) indicate that for best results on a disturbed high-elevation site, nitrogen should be applied at a rate of 60 pounds per acre per year for at least 4 consecutive years. Chambers et al. (1987) reported that the residual quantities of nitrogen, phosphorus, and potassium on revegetated alpine areas in Montana decreased rapidly after fertilizer application. Incorporation of organic matter was viewed as an important step towards retention of these elements in a viable system of nutrient cycling.

In some cases higher seedling mortality was noted on fertilizer plots in disturbed alpine sites because of an initial pulse of nitrogen and phosphorus, followed by a rapid decline in nitrogen. This decline in fertility following a nutrient pulse can result in decreased nutrient absorption, photosynthesis, and growth, and in turn, cause greater susceptibility to other stresses (Chapin 1980).

Reeder (1990) stated that inorganic nitrogen fertilizer added to mined lands was more prone to leaching and volatilization losses because plant and microbial communities were less active after disturbance. This raises the concern of the impact on surface and ground waters of increased dissolved nitrogen levels related to heavy nutrient loading on disturbed sites.

Rennick et al. (1984) did not recommend using inorganic fertilizers on topsoiled coal spoils in Montana because of increased invasion by weedy species and a loss of plant community diversity. Brown et al. (1984) stated that high seeding rates and heavy application rates of inorganic fertilizer could produce closed plant communities and impede successional development in alpine ecosystems.

Organic Matter

Soil organic matter consists of plant and animal residues in various stages of decomposition, living soil organisms, and substances synthesized by these organisms. This material is important to the development of mineral soils and is one of the major keys to soil productivity. Soils differ in organic matter content from region to region. Semiarid areas usually have topsoil with less than 2% organic matter.

The chemical composition of soil organic matter is categorized in three major groups: polysaccharides, lignins and proteins. These three classes of materials are sources of food for soil micro-organisms (Ludwick 1990). Organic matter is primarily carbon (approximately 58% by weight) and contains a large reservoir of essential plant nutrients (Tisdale and Nelson 1985). The concentration of nitrogen in plant material is usually greater than 1% and may exceed 3% (Reeder and Sabey 1987).

Organic matter content of soils directly affects moisture-holding capacity by increasing water absorption and retention (Brandt and Hendrickson 1991). It also enhances nutrient availability by increasing cation exchange capacity, and provides a steady supply of plant nutrients through decomposition and mineralization (Smith et al. 1987).

High seedling mortality has been attributed to the formation of needle ice and soil drought conditions at high-elevation sites (Roach and Marchand 1984). Cochran (1969) found that organic amendments enhanced seedling establishment by decreasing soil water loss and increasing soil surface temperatures. Organic amendments also alter surface characteristics which help prevent surface wind erosion of soil and seeds.

Incorporating organic matter into mineral soils and spoils can increase plant growth (Joost et al. 1987; Smith et al. 1987; Ludwick 1990). Brown et al. (1978) recommended application rates of 2,000 to 4,000 kg/ha^{-1} of organic matter to improve water and nutrient availability in xeric, sterile alpine spoils. However, a cost effective and environmentally acceptable source of organic matter suitable for high-elevation reclamation projects can be difficult to find.

Benefits of Compost

The benefits of composted municipal wastes on disturbed sites are derived primarily from the compost's structure, organic carbon pool, nutrient content and form, and microbiological inocula (Brandt and Hendrickson 1991). The relative contributions of each type of compost to soil characteristics and plant growth will vary with the materials and bulking agents used in the composting process. Compost dry matter based on plant and animal wastes contain a full range of plant macro- and micronutrients generally suited for plant growth. All composts provide a large amount of degraded organic matter which may improve the friability of fine-textured soils and the moisture-holding capacity of coarse-textured soils (Bradshaw and Chadwick 1980).

One of the principal benefits of compost additions to disturbed soils is the initiation of nutrient cycling. This results from the inoculation into sterile soils of microbial decomposers present in the compost. The supply of mineral nitrogen in soils is constantly replenished by microbial mineralization of soil organic matter. In this process, certain soil microorganisms use organic substances as an energy source and nitrogen from the organic material as a building block for microorganism protein. Dead microorganisms subsequently decay and release nitrogen for microorganism and plant use. Studies of compost and municipal sludge amendments to soils have documented increased soil microbial biomass and nutrient cycling (Fresquez and Lindemann 1982; Whitford et al. 1990). Microbial processes are so important to soil recovery that the activity of microorganisms may be used as an index for the progress of soil genesis in minespoils (Seaker and Sopper 1988).

The microbial decomposition of organic matter is also one of the most important factors in soil structure development. Soils with good structure provide the best conditions for supplying water and nutrients to plants. The best water and nutrient regimes occur in soils with granular structure with aggregate sizes from 1 to 2 mm (Smith et al. 1987). Brandt and Hendrickson (1991) stated that additions of 25% compost by volume could alter physical characteristics of soils. Organic material has little effect on soil structure, however, unless microbial activity produces stable soil aggregation. Fungi and actinomycetous produce mycelia and have metabolic processes that synthesize complex organic molecules. These decomposition products, in combination with the mechanical binding action of cells and filaments from microorganisms, produce stable soil aggregates.

Another important benefit of compost additions to disturbed soils is the inoculation into sterile soils of symbiotic mycorrhiza (Brandt and Hendrickson 1991). These organisms form symbiotic associations with root systems of many plants and their presence is crucial for water and mineral uptake by some higher plants (Williams 1979; Whitford et al. 1990).

Surface mining can disrupt mycorrhiza and other microorganism populations in soil when plant communities are temporarily destroyed. Microbial population disruption is increased when top-soils are stored for long periods of time or mixed with spoil and subsoil material. Repopulation of the microbial biomass in such areas can be very slow because fungi and bacteria do not readily adapt to chemical and physical changes in disturbed soils (Smith et al. 1987).

Addition of composts, which are high in organic matter content, can improve water infiltration, reduce evaporation, improve drainage in fine-textured soils, and encourage more extensive and deeper root systems (Brandt and Hendrickson 1991). Other organic amendments, such as straw and wood-fiber mulches, can also have positive effects on soil structure when they are incorporated into the soil column (Schuman and Belden 1991). These amendments, however, may be low in those nutrients commonly supplied by compost. Their high carbon content could actually decrease nitrogen availability for plants because the amendments stimulate microorganism growth rates with a subsequent increase in nitrogen uptake. (Simms 1990). Consequently, rates of decomposition and nutrient cycling in soils receiving only mulch will generally be lower than compost-treated soils (Brandt and Hendrickson 1991).

Sewage Sludge and Composted Municipal Waste in Reclamation

Numerous studies have shown that amending soils with organic materials such as sewage sludge increases soil organic matter content, and improves soil structure and long-term fertility (Bradshaw and Chadwick 1980; Khaleel et al., 1981; Joost et al. 1987; Simms 1990). Many of these studies were carried out on agricultural lands, but sewage sludge has also been extremely successful when used as an organic amendment in minespoil reclamation (Hortenstine and Rothwell 1972; Seaker and Sopper 1988; Skousen 1988).

Researchers in Philadelphia, Pennsylvania used a "mine mix" of 50 percent dewatered sludge and 50 percent sludge compost to successfully reclaim strip mined lands (Alpert and Segall 1990). Sabey et al. (1980) demonstrated the benefits of sewage sludge in the reclamation of disturbed oil shale lands in northwestern Colorado. Sewage sludge also enhanced the growth of native shrubs in spoils of a copper mine in Utah (Sabey et al. 1990). Norland et al. (1991) utilized composted municipal waste to increase vegetative establishment on coarse taconite tailing on Minnesota's Mesabi iron range. Four applications of municipal waste compost, applied during a two year period, significantly improved soil nutrient characteristics and increased plant growth on sterile phosphate sand tailings in Florida (Hortenstine and Rothwell 1972).

Several researchers found that municipal sludge could be used to successfully revegetate strip-mined land in Pennsylvania (Sopper and Kerr 1981; Seaker and Sopper 1988). Repeated sludge applications had no adverse effects on vegetation, soil, or groundwater quality and there was little risk to animal or human health from heavy-metal contamination.

Amendments such as sewage sludge and composted municipal waste have proven valuable in reducing metal toxicities in acid tailings. A combination of sewage sludge and fly ash were used to revegetate an acidic and heavy metal contaminated superfund site in Pennsylvania (Garvey and Donovan 1992). Plass (1982) successfully revegetated acidic wastes (pH of 4.0) by applying 20 metric tons of organic matter per hectare. Mushroom compost and paper-mill sludge were used to successfully revegetate acidic (pH 3.3 to 4.1) coal-mine spoils in southeastern Ohio (Vogel and Rothwell 1985).

Three Amax Inc. molybdenum mines at timberline along the continental divide in Colorado have had active reclamation programs for years. Researchers have found that a mature soil is prerequisite to achieving self-sustaining vegetation. The most economical and beneficial soil amendments were an initial application of 44.8 metric tons per hectare of both sewage sludge and wood-chips, followed two or three years later by an additional 22.4 metric tons per hectare of sludge (Brown

1976). Although this procedure has been successful, nitrogen levels must be carefully balanced. Soil microbes consume more nitrogen than plants during decomposition, which may result in soil nitrogen deficiencies. A compost is more chemically stable and less likely to mobilize nitrogen when added to soil, after it has decomposed over a longer period of time (Sikora and Sowers 1985). Composting the sewage sludge and wood wastes at lower elevations and transporting the finished product to a high-elevation site could speed decomposition and eliminate some fluctuation in nitrogen cycling.

Wood-chip/municipal sludge composts were tested in revegetation experiments in an arid region of southeastern Washington. Compost was incorporated into soils that failed to support growth the previous year. Plant survival and growth on the composted sites was more than twice that of the untreated controls. Grass density on the composted sites was three to five times greater than controls. Sludge compost treatments also produced greater revegetative success than combinations of straw mulch and low-rates of fertilizers (Brandt and Hendrickson 1991).

A review of the literature substantiates the idea that composted municipal wastes have properties that are beneficial in reclaiming mining disturbances. This project was designed to determine whether this increasingly available waste product has a practical use in restoring alpine and subalpine ecosystems.

Compost Availability

The growth and development of sludge and yard waste composting facilities has expanded rapidly in recent years as communities across the country search for ways to reduce solid waste and increase the life spans of dwindling landfill space. There were an estimated 800 to 1,000 municipal yard waste composting facilities in the United States in 1988 with the number growing steadily (Glenn 1988). In 1987, there were 90 sludge composting projects nationwide, with 61 operating plants. In 1989 there were 227 sludge composting projects, and 119 operating plants (Goldstein and Riggle, 1989). Commercial composting operations have proven themselves to be a cost effective and environmentally sound recycling technology (Taylor 1989).

Although there has been substantial research on the use of sewage sludge and compost in mine reclamation at low elevations, use of sewage sludge compost at high-elevation sites in the Western United States has not been thoroughly and scientifically tested. Further investigation is needed to evaluate how different types of municipal compost effect the establishment of vegetation on disturbed high-elevation sites.

MATERIALS AND METHODS

Site Description

The Basin Creek gold mine, a heap leach operation, is located approximately 25 km southwest of Helena, Montana (Figure 1). Operation of the mine will result in the disturbance of approximately 156 ha. The mine includes public and private land in the Deerlodge and Helena National Forests and straddles the continental divide at elevations from 2,260 to 2,380 m (Figure 1).

Soils in the project area are primarily gravelly and sandy loams in the early stages of development with pH values from 4.5 to 7.5. Parent materials consist of quartz monzonite at lower elevations and porous lithic tuff and rhyolite flows at higher elevations. Prior to disturbance the soil at the study site was classified as a Typic Cryoboralf, coarse loamy, mixed (Noel 1989). Mean annual precipitation averages 760 mm per year.

The subalpine site is dominated by dense stands of lodgepole pine (*Pinus contorta*) with common beargrass (*Xerophylum tenax*) and grouse whortleberry (*Vaccinium scoparium*) the dominate ground cover. Mining disturbance completely destroyed the plant community which previously occupied the study site.

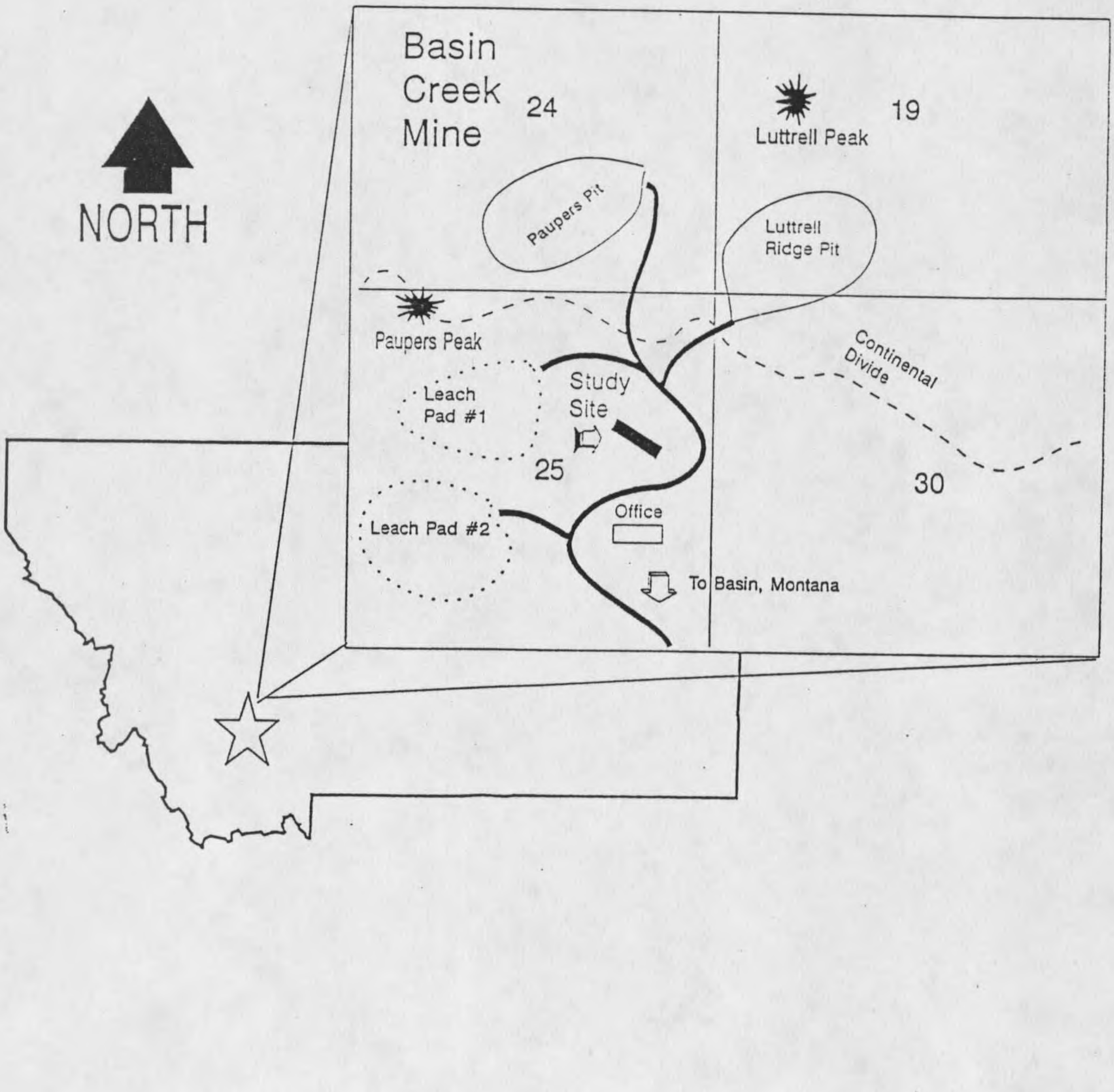

Figure 1. Location of Basin Creek Mine study site.

Field Plot Design

In late June of 1991 project implementation began on a 0.5 ha area of the mine, previously used as a haul road (Figure 1). The area was recontoured to a 1 to 8% grade with a southwesterly exposure. Salvaged topsoil was spread over the area to a depth of 15 to 20 cm. Plots with dimensions of 3 by 3 m were established in a randomized block design (Figure 2). One meter buffer zones were maintained between all plots. Nine treatments and two controls per block were replicated three times for a total of 33 plots.

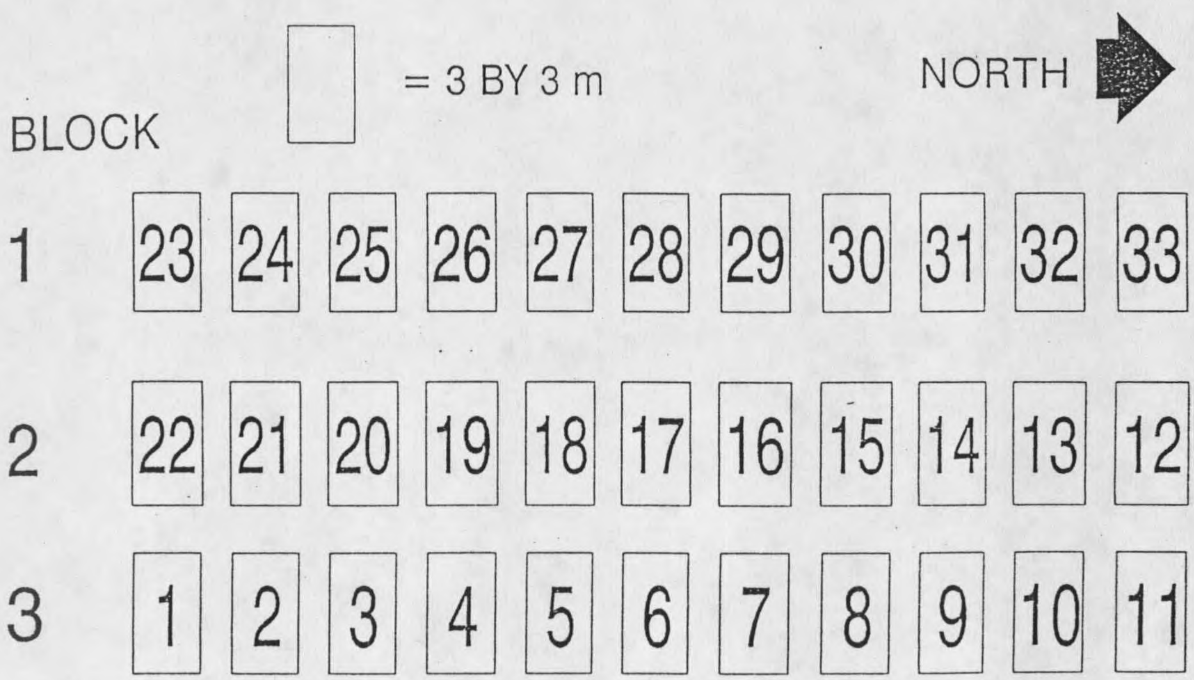

Figure 2. Randomized block design for treatments.

Amendment Recommendations

The Basin Creek Mine began using 9.5 Mg/ha of surface applied sewage sludge compost (EKO Compost) as an amendment during the fall of 1990. This application rate was based on recommendations from greenhouse vegetation trials conducted for the mine (Noel 1990). Soil crusting had been identified as a possible factor contributing to poor vegetative growth on reclaimed areas at the mine. In these trials, incorporated compost appeared to increase vegetative yields and prevent soil crusting. The rates of compost used in this study were based on recommendations from other studies, (Plass 1982; Vogel and Rothwell 1985; Seaker and Sopper 1988; Brandt and Hendrickson 1991). EKO compost and the Bozeman compost were selected for use in this study because they were the only composts available in the region surrounding the Basin Creek Mine, and were produced in large enough quantities to be effective in the reclamation of a disturbed mine site.

Application Rates And Methods

Sewage sludge compost (EKO) is produced commercially in Missoula, Montana. The compost operation is located adjacent to the municipal sewage treatment facility and utilizes sewage sludge combined with wood product wastes and yard debris. The three-phase composting process is completed in nine months. The final product is screened; 1 cm for gardening, 2.2 cm for mining and a double 1 cm screening for hydromulchers. Mine compost was transported in cubic yard bags to the mine site.

EKO compost was applied at two rates, 76 Mg/ha and 152 Mg/ha. This is equivalent to compost being spread at 1.25 cm and 2.5 cm thick layer over the surface of the plots. The two EKO compost rates of 76 Mg/ha and 152 Mg/ha were surface applied and both rates were incorporated to a depth of 10 cm with a rototiller.

Bozeman Compost (BOZ) is produced by the municipality of Bozeman, Montana at the local landfill. The compost used in this study was made up of an estimated 30% grass clippings, 30% leaves, and a 40% combination of straw, hay, manure, hedge trimmings, and wood chips. Finished compost is produced in 20 months and is provided free to the public or used as a soil amendment in rehabilitation of the landfill site.

Bozeman compost, like EKO, was applied at two rates; 76 Mg/ha and 152 Mg/ha. This is equivalent to the compost being spread 1.25 cm and 2.5 cm thick over the surface of the plots. The compost was incorporated to a depth of 10 cm with a rototiller. No surface applications were made with this amendment.

Mine Combo (MINE CMBO) is the name given to a combination of amendments used by Basin Creek Mine. This mine applies the amendments with a hydromulcher for revegetation projects. A hydromulcher was not available for this study, consequently replicated amendment rates were broadcast by hand.

Mine Combo amendments consist of EKO compost double-screened through a 1 cm mesh and hydromulched at 9.5 Mg/ha. This is equivalent to compost being spread 1.6 mm over the surface of the plots. Pro-Rich dehydrated poultry waste and Silva-Fiber, a wood fiber mulch, were combined with the compost. Application rates were 112 kg/ha Pro-Rich dehydrated poultry waste with $N-P_2O_5-K_2O$ content of 14-5-5 percent respectively and 2.2 Mg/ha of Silva-Fiber.

Rates of nitrate fertilizer (FERT), were based on the total Kjeldahl Nitrogen (TKN) analysis of EKO Compost. Fertilizer rates were equivalent to 0.7% total nitrogen by weight, present in the two rates of EKO Compost, 76 Mg/ha and 152 Mg/ha, which were applied in this study. This resulted in fertilizer application rates of 0.51 Mg/ha and 1.02 Mg/ha. The granulated fertilizer was broadcast by hand and raked into the soil surface.

Two controls (CONT) were used. CONT I had no amendments or seed and CONT II was seeded with the Basin Creek seed mix. No amendments were added to CONT II, however (Table 1).

Seed Mix and Rate

The plots were rototilled to a depth of 7 to 10 cm for seed bed preparation. All plots were broadcast seeded by hand with the Basin Creek Mine seed mix (Table 2). Seed was lightly raked into the amended surface soil.