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THE USE OF DIGESTED SEWAGE SLUDGE AS AN AID TO RECLAIM AND REVEGETATE SURFACE/STRIP MINES AND MINE SPOILS

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Abstract

Ecosystem restoration, and satisfactory revegetation of strip-mined areas provides an amiable complement to the disposal of treated sewage sludge. Although surface mining is often the most economical method for removing mineral resources, its detrimental impacts on the land surface landscape and ecological environment is and will continue to be a concern. The problem of reclaiming lands disturbed by mining activities is extremely important, as is the sustainability of these reclaimed lands. Stringent regulations, in combination with aie cost of commercial fertilizers, make the search for fertilizer substitutes and alternate soil amendments vital. The use of anaerobically digested de-watered sewage sludge as both a fertilizer source and a soil organic matter amendment in mine reclamation can provide the solution to two pressing and use-related problems: the disposal of treated sewage sludge in a beneficial re-use function and the reclamation and revegetation of mine spoils. Sewage sludges can be regarded as a recyclable source of nutrients and organic matter, and can aid in revegetation and initiation of a sustainable soil humus complex.

The purpose of this symposium submission is to review the current state of knowledge on the use of sewage sludges for revegetation and reclamation *of* surface/strip mines and mine spoils. The long-term sustainability of reclamation efforts utilizing sludges will be detailed by assessing related research projects and operational trials. Results of a joint GVRD/UBC investigation of the use of sewage sludge as an organic forest fertilizer will be presented. Potential environmental impacts are reviewed including effects on vegetation, soil properties, water quality and animal health.

INTRODUCTION

Society is increasingly beset by environmental problems arising from the management and utilization of resources. Conversely, the management of these resources is becoming increasingly complex as a consequence of the rapidly changing attitudes of the public towards resource utilization, sustainability and the environment. The challenge lies in the ability to increase our level of understanding of the components and processes of our environment and the nature of environmental problems, while contributing to the development of scientifically sound and socially acceptable strategies by which the resources demanded by society can be provided in a sustainable manner. Alterations to the environment necessary for the acquisition of these resources must be kept at a minimum level of impact both in duration and intensity. The revegetation and reclamation of mine tailings and spoils and the sustainability of this vegetation provide just such a challenge.

Revegetation of disturbed lands is a problem of current concern, particularly with stringent regulations governing rehabilitation. The major goals of surface mine revegetation are to reduce erosion, stabilize the mine soil, and produce a site suitable for the desired post-mining land use (Roberts *et al.* 1988). Large amounts of lime, frequent applications of inorganic fertilizer and seed are usually needed. On many sites soil amendments, mulches, compost and/or irrigation are required in an attempt to move the site into a permanent, self-sustaining vegetative community.

In common with many other parts of the world, another major problem facing B.C. society today is how to dispose of treated sewage sludge. The Greater Vancouver Regional District, encompassing eighteen municipalities alone currently produces 60 dry tonnes per day, and this mass is expected to more than double by the year 2036 as a result of population growth and the institution of secondary wastewater treatment (GVRD Sludge management alternatives, 1990). Disposal options include landfill, incineration, ocean dumping and forms of land application. Each option has inherent problems. Landfill disposal is beyond the capacity of existing landfills, and land use is such that increasing the size and amount of landfills, is not feasible. Incineration is very expensive, energy inefficient, aggravates air quality and creates an ash disposal problem. The environmental impact of ocean dumping is no longer acceptable. Land application provides the only option that can give consideration to the environmental protection aspects of sludge disposal and, at the same time consider recycling of sludge as a resource and environmental improvement measure. Both of these problems - sustainable revegetation of mine spoils and tailings and disposal of sludge may be alleviated by the utilization of treated sewage sludge as a tool to successfully rehabilitate and revegetate disturbed areas (Sopper *et al.* 1981).

During the past two decades, extensive research has been conducted in the United States on utilizing treated sewage sludge in reclaiming mine spoils and tailings, and assisting in the development of vegetative communities on mine soils (eg. Boesch 1974; Brooks *et al.* 1979; Hinesly *et al.* 1976; Stucky & Bauer, 1989). Treated sewage sludge has been shown to be an excellent soil conditioner. It can be superior to most commercial fertilizers in that it is organic, and contains additional micronutrients necessary for plant growth. The major chemical constituent of sewage sludges, apart from carbon, hydrogen and oxygen, is <u>nitrogen</u> - the nutrient most commonly limiting plant growth. Sewage sludge releases these nutrients slowly, provides organic matter to the soil increasing soil water and nutrient holding capacity and improves soil structure (Epstein *et al.* 1976). There exists an amiable coincidence between what is required to revegetate mine soils and the material society produces as a "waste" and must be disposed of. There is, however, one possible disadvantage. Sewage sludges have the potential to contain, at various concentrations, every element and compound found in wastes from both domestic and industrial sources, and include "heavy" or trace metals. Concerns exist surrounding the potential of trace metals to enter the human food chain (Horvath 1972; Blessin & Garcia 1979).

It would be extremely beneficial to discover a method of removing valuable minerals, ores and hydro-carbon sources, and process them into a useable form without the need to disturb the land, and produce a "waste" byproduct. Similarly it would be equally beneficial to not need lavatory facilities, and resulting treatment plants, wherever society decides to reside. Unfortunately these are not possible.

Numerous successful projects demonstrate the; value of using sewage sludge in reclamation projects, yet in British Columbia initiation has been very slow. The largest obstacle appears to be a combination of the NIMBY syndrome, coupled with a lack of knowledge on the part of the general public on the impact of sewage sludge applications on vegetation, water, soils and animals. Treated sewage sludge is available in large quantities from major urban centers, the only potential drawback may be economics of transportation.

Excellent review articles on utilization of sludge in mine reclamation include Sopper and Seaker, 1982; Halderson and Zenz, 1978; and Berry, 1986. Numerous relevant papers may be found in the published proceedings of symposium including "Land Reclamation and Biomass Production with Municipal Wastewater and Sludge" (Sopper *et al.* (eds.)), "Utilization of Municipal Sewage Effluent and Sludge on Forest and Disturbed Land" (Sopper & Kerr (eds.)) and "The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes" (Cole *et al.* (eds.)). Several papers included within these proceedings are cited within this submission.

This paper will briefly review the impaict of sludge applications to mine soils/tailings on the vegetation, soil properties, water quality and animal "health". Major section headings follow the topics of potential impact and resulting public concern as identified in Sopper and Seaker (1982). An additional list of related literature is included for further information and future reference. As it is impossible to review such a large body of information in a limited space only "key" references have been cited. The initiation of a joint Greater Vancouver Regional District / University of British Columbia research program addressing the impact of sludge fertilization in forestry will be described in brief.

IMPACT ON SOILS

Soil Biology

The immediate goal of reclamation is to establish a vegetative cover that will prevent soil erosion, however in the long term the ultimate goal is soil ecosystem development and sustainability. Minespoils lack microbial activity and organic matter (Fresquez & Lindemann 1982). Soil microorganisms have an important role in the reclamation of spoils, especially in the creation of soil organic matter and the accumulation of nitrogen for plant growth (Cundell 1977). Microbial processes involving humification, soil aggregation and nitrogen cycling are essential in the establishment of a sustainable vegetative community (Visser 1985). One problem with revegetating mine spoils is the extreme acidity that can release metals such as Zn, Cu, Cd and Pb from the spoil itself into soil solution in concentrations that would be inhibitory to soil microorganisms (Mills 1985). Lawrey (1977) attributed reduced respiration and fungal populations in strip mine spoil to high levels of metals coupled with low nutrient levels and soil reaction. In anaerobically digested de-watered sludge, sludge metals are bound to the organic components as sulfides, chlorides, carbonates, hydroxides and other compounds not readily soluble. Establishment of dense vegetation achieved by sludge amendment greatly increases water holding capacity and reduces acid formation and the release metals from the spoil (Seaker & Sopper 1988b).

Sundberg *et al.* (1979) found, in a study on the Palzo tract in Illinois, fungal populations in unreclaimed spoil to be only slightly less than those in unmined agricultural soils. Application of sludge as a revegetation aid resulted in a tenfold increase in fungal activity and was attributed to an increase in pH, food supply and better soil moisture retention. In a study of five coal surface mines reclaimed with sewage sludge compared with one reclaimed with conventional fertilizer Seaker and Sopper (1988a) found that populations of aerobic heterotrophic !bacteria, fungi and *Nitrobacter,* and the soil respiration rate were highest on the sludge-amended sites one year after application. On four year old sites reclaimed with sludge values decreased, but remained within the values reported for undisturbed soils. Actinomycete populations peaked at 3 and 4 years following application, while populations of *Nitrosomonas* were not related to age of the site;. The decomposition rate was lowest in the first year following application, and increased substantially with site age. They concluded that ecosystem recovery on the sludge-amended site appeared to be occurring at a more rapid rate than on the fertilizer-amended site, which after 5 years exhibited sparse microbial populations of limited diversity and low activity.

In contrast to Lawrey (1977), Seaker and Sopper found the microbial populations in the sludge amended spoils were not affected by heavy metals when compared with populations in undisturbed soils.

Through intensive reclamation and management techniques mine spoils can recover to possess similar microbial and fungal characteristics to that of undisturbed lands. Intensive management dictates annual fertilizer inputs, usually for several years. Without annual maintenance, vegetative cover often deteriorates as a result of slow microbial development and poor nutrient cycling. Sludge amendments quickly increase the numbers and activity of microorganisms, whose activities enhance the development of soil conducive to sustainable plant growth. The use of sewage sludge provides the requirements for the development of an indigenous microbial community which is the key factor in providing sustainable site stability through biogeochemical cycling of energy and nutrients.

Application of sewage sludge to mine spoils adds nutrients to the soil, improves soil structure and assists in the development of a sustainable microbial population; however it also introduces trace metals at various concentrations. In many soil types earthworms are the principal organisms involved in translocating and mixing soil constituents and there exists concern surrounding possible bioaccumulation of trace metals in earthworms living in sludge-amended soils, and the possibility of this bioaccumulation as a route to contamination of birds and animals. Helmke *et al.* (1979) showed that worms in soil treated with sludges that contain high concentrations of metals may contain high concentrations of metals and suggested the need to further examine the potential for contamination of the food chains by this route. Studies have shown worms can concentrate Cd from soils experimentally amended with sewage sludges containing high levels of Cd (Anderson 1979; Hartenstein *et al.* 1980). Van Hook (1974) suggests that worms are useful indicators of the availability of soilborne metals to animals.

Beyer *et al.* (1982) conducted an experiment to determine if earthworms are important in transferring metals to soil and wildlife. Metals in earthworms *(Lumbricidae)* from agricultural fields amended with sludge and from control fields were examined, Earthworms from the sites amended with sewage sludge contained significantly more Cd, Cu, Zn and Pb than did earthworms from control sites, but the concentrations were variable in relation to the sludge metal concentrations. Cd and Zn were concentrated in earthworms relative to the soil, and Cu, Pb and Ni were not concentrated. Low pH was deemed responsible for increased availability, and liming decreased Cd concentrations. Antagonism between Zn and Cd was evident in that high concentrations of Zn in the soil substantially reduced Cd concentrations in earthworms.

Pietz *et al.* (1984) initiated a three year study on metal concentrations in earthworms in selected mine soil and non-mined fields at Metro Chicago's Fulton County land reclamation site. Earthworm metal concentrations generally increased with time in all treated sites. The decreasing order of metal accumulation by earthworms in all sludge-amended fields samples was Cu>Cd>Ni>Cr>Pb>Zn. In agreement with Beyer *et al.* (1982) Pietz and coworkers found earthworm Cd and Cu accumulations in sludge amended fields was significantly related to the current amount of sludge applied metals. Concentrations of Ni, Cr and Pb were not related to sludge applications. They conclude that higher Cd and Cu concentrations in earthworms from sludge amended fields may pose a potential hazard to predators. The biological transfer of earthworm metals to predators is reviewed in the animal health section.

Soil Chemistry

When sewage sludges are applied to mine spoils, several modifications of the soil chemical properties occur. These properties include soil reaction, cation exchange capacity and availability of plant nutrients and metals.

Joost *et al.* (1981) monitored the pH change of coal refuse and found it to increase from 2.6 to 5.3 without the addition of limestone when applied with sludge at 450 to 900 mt/ha. Sludge was more effective than 180 mt/ha of limestone at raising pH. Sutton and Vimmerstedt (1974) identify sewage sludges to be more efficient in modifying mine soil pH. Additions of limestone initially increase the pH on acid mine spoils but without the addition of sludge the pH declines as minerals are oxidized. Sludge applications up to 627 mt/ha increased the pH of strip mine spoil from 3.5 to 6.7 and was maintained for two years (Stucky *et al.* 1980).

Cation exchange capacity is improved by sludge addition to spoils as a result of the high cation exchange capacity of organic matter. Cation exchange capacity is an important factor in determining the availability of cations added to soil as constituents of soluble salts, but may not significantly affect the uptake of essential and nonessential trace elements by plants (Sopper & Seaker 1982).

The effects of sludge incorporation on the quantity and availability of plant nutrients varies with the "quality" of the sludges. Sludges usually supply considerable nitrogen and phosphorus, but little potassium. Potassium deficiencies may become evident in plant communities established on sludge rehabilitated spoils. This again is dependent *on* the previous soil parent material and concentrations of potassium in the sludge.

The trace metal constituents of sewage sludges result in an increase of trace metal concentrations in a sludge applied mine spoil, although in many cases this addition is insignificant. Organic matter additions and an increase in pH decrease the availability of Fe, Mn and Al (usually present in high concentrations in mine spoils). Kardos *et al.* (1979) identified the input of phosphorus (from within the sludge) into the mine soil tended to "tie up" and detoxify Fe, Al and Mn in the rooting zone.

Sewage sludges in combination with lime applied to acidic coal refuse material increased the availability of N, P and some K to growing plants, and modified the pH, affecting the availability of metals to plants. Soil solution levels of metals were reduced by precipitation, ion exchange, surface absorption and complexation reactions with the; applied sludge. In addition to the pH changes Pietz *et al.* (1989b) states that an antagonistic effect between sludge-applied P and metals may also reduce the availability of metals to plants.

Soil Physics

Khaleel *et al.* (1981) provides an excellent review on changes in soil physical properties due to organic waste applications, including sewage sludge. The high concentration of organic matter in sewage sludge benefit the soil physical characteristics by decreasing bulk density, dramatically increasing the water holding capacity, and decreasing soil temperatures on sand and gravel spoils. Direct relationships can be established between changes in bulk density and water-holding capacity as a function of net increase in soil carbon (organic). The decrease in bulk density as a result of sludge applications is due to a dilution effect resulting from the mixing of the added organic matter (OM) with the more dense mineral fraction (Epstein *et al* 1976). Kladivko and Nelson (1979) have reported increased water holding capacity and a weight basis at both field capacity (-1/3 bar) and wilting point (-15 bars) with an increase in sludge application rates. Water holding capacity of soils is controlled primarily by the number of pores and pore size distribution and the specific surface area of soils. Because of increased aggregation, total pore space is increased. Furthermore, as a result of decreased bulk density, the pore size distribution is altered and the relative number of small pores increases, especially for coarse textured mine soils.

Pagliai *et al* (1981) found that anaerobicaily digested sludges provided the largest increase in total porosity and stability of soil aggregates as assessed by electro-optical image analysis. Joost *et al.* (1987) found in a mine soil revegetated with the aid of sewage sludge that organic matter decreased by 35% two years after the plots were established, while the proportion of sand-size water-stable aggregates increased over the same period. Changes in physical properties of mine soils amended with sewage sludge greatly assist in the development of a vegetative community.

IMPACT ON WATER QUALITY

Application of sewage plant sludges to mine spoils provide a solution to the sludge disposal problem in addition to the problem of revegetation of spoils. The application of large volumes of sludge may pollute the groundwater as spoils are unconsolidated, often very porous and chemically very heterogeneous. The concern over a potential decline in groundwater quality extends to adjacent ephemeral streams and creeks, ponds and reservoirs.

On athracite and bituminous strip mine soils Kardos *et al.* (1979) found in lysimeter leachate collected over 1m below a vegetation community established on a sludge amended spoil had lower concentrations of Fe, Al, and Mn than in control spoils. McCormick and Bordon (1973) found initially high S levels in percolate water that decreased to below that of the control areas. Haghiri and Sutton (1982) found in Ohio strip mines amended with large quantities (716 mt/ha) of sludge leachates as compared with controls did not differ significantly in Cu, Ni and Mn concentrations, and actually decreased with increasing time after application. Cd and P were below detection limits in both the control and treated mine spoils. At the Palzo tract, after application of liquid digested sludge concentrations of Fe, Mn, Al, Zn, Cu, Pb and SO_4 in subsurface drainage water was reduced (Boesch 1974).

Peterson *et al.* (1979), monitoring water quality on the Fulton county project in Illinois found that the addition of sludge increased nitrate - N marginally, and the annual concentrations of nitrate - N, Cd, Zn, Cu, Co and Pb were within EPA drinking water limits for the two watersheds tested. Faecal coliform counts did not increase as a result of application, and actually decreased with time. The authors theorize this is a result of a reduction in livestock grazing on the site.

The use of sewage sludge to assist in the revegetation of mine spoils often improves the quality of the leachates. A vigorous plant community plays an important role in the replenishing of organic matter as the sludge begins to decompose. The addition of sewage sludge plays an important role in increasing the pH and buffering capacity of the spoil, which in turn controls the solubility of sludge and soil metals into soil water.

IMPACT ON FAUNA

With Cd, Cu and Zn accumulating at significant amounts by worms in sludge-amended soils there exists the potential to pose a hazard to their predators. The significance of an increased metal accumulation in these predators is, for the most part, unknown because there are few published studies relating to metal concentrations in earthworms to toxic effects in predators. Birds are predators of earthworms and there are some studies of their metal accumulation.

Gaffney and Ellertson (1979) reported on accumulation potential in redwinged blackbirds *(Agelaius phoeniceus).* Redwinged blackbirds nesting on the sludge-reclaimed Palzo strip mine (background see Boesch 1974; Roth *et al.* 1979; Stucky and Bauer 1989) were analyzed for Cd, Zn and Pb in various tissues and found no significant concentration differences in Cd, Zn or Pb in brain, liver, kidney and muscle between birds living in undisturbed areas or on strip mines reclaimed with inorganic fertilizers. Higher kidney Cd concentrations were observed on the sludge sites, however in some birds Cd concentrations were higher in control areas. Zn-Cd interactions make single element comparisons difficult. Relative ratios of the various metals in question would make for a better understanding of these interactions.

Following the earthworm study at Chicago's Fulton reclamation site Hinesly *et al.* (1976) fed pheasants *(Phasianus colchicos)* corn grain from soils amended with sewage sludge. They reported a significant increase of only Cd in duodenal, liver and kidney tissue, and that grain consumption and weight changes were not related to chemical composition of the grain. The authors conclude that the consumption of meat from these animals would present little, if any, potential health hazard to humans. Although the Cd levels did increase significantly compared to the control animals, the maximum levels of Cd in the tissues were still comparable to those reported elsewhere for animals fed a normal diet.

Levels of heavy metals in vegetation and tissues of cottontail rabbits *(Sylvilagus floridanus)* were compared between those animals from a non-treated mine site and a strip mine treated with sewage sludge. Concentrations of Cd, Cu and Zn were higher in vegetation on the sludge treated site. Zn in femurs of cottontails was higher on the treated site, but most metals were comparable to those from a non-treated mine site and a non-mixed area. Dressier *et al.* (1986) conclude that overall, cottontail rabbits did not accumulate metals on the sludge treated site at hazardous levels.

Beardsley *et al.* (1978) proposes that field voles *(Microtus agrestis)* are promising indicator species by which to estimate the hazards to wildlife or grazing animals of trace metal pollution. Voles are now commonly used as test animals (Smith & Rongstad 1982). These small mammals are common herbivores (primary consumers) of agricultural and natural grassland communities. Their summer diet of succulent vegetation make them a good indicator of potential metal transfer from plant growth in the period of time concurrent with sludge application.

Anderson *et al.* (1982) found mean Cd concentrations in livers and kidneys of voles from sludge treated fields in the second year of application to be significantly higher than controls. Cd concentrations in voles from inorganic fertilizer treated fields did not differ from controls. There was no treatment differences in Pb or Zn concentrations, nor in individual organ or whole body weights. They conclude the short term effects on these mammals of sludge application to land appears to be benign, despite accumulation of metals in vital organs.

In another vole study (Alberici *et al.* 1989) found concentrations of Cu, Zn, Co, Cd and Ni in vole tissues were not significantly different between a control and a strip mined site reclaimed with the aid of sewage sludge. They did find, however, *Cr* concentrations in the kidney and bone and Pb concentrations in the liver and bone were higher on the control site than on the treated site.

The biological transfer of metals from vegetation and earthworms to primary consumers and predators suggests that there may exist a small hazard, although the previous studies minimize the potential for impact. Of the 'major' trace metals (Cd, Co, Cr, Cu, Ni, Pb and Zn) all but Cd and Pb are generally considered essential for body function (Dressier *et al.* 1986). Studies of the uptake of trace metals in wild animals are complicated by three factors: quantification of foods consumed, availability of these elements in plant materials ingested by animals, and interaction among the trace metals. Additional research is required to establish a baseline background data set on normal metal concentrations in biological systems.

Another aspect of animal nutrition and health is the quality of forage produced should the reclaimed land be used for livestock grazing. Sludge amendments on mine spoils in Illinois significantly improved corn grain quality as measured by protein content (Blessin & Garcia 1979). Plant uptake of metals consumed by grazing animals can increase the potential for biomass accumulation. Fitzgerald (1979) states grazing animals exposed to heavy metals show toxic reactions quickly. In this study Fitzgerald found the concentrations of heavy metals in tissues of animals grazing on sludge grown forage were not significantly different from controls.

In addition to trace metal accumulation, another health related concern is that of pathogenic organisms in sludge. Pathogens have not been found to be a serious health risk in the utilization of anaerobically digested sludge (Sopper & Seaker 1982). Risks to human health by microorganisms are judged to be minimal under conditions of well-defined treatment, transport and management of application (Sorber & Moore 1986).

VEGETATION RESPONSES

Mine soils can be significantly improved both in vegetative productivity and in fertility with the addition of sludge compared with the addition of inorganic fertilizers. There exists a vast quantity of literature detailing the response of various species to sludge reclamation projects. Forage crops, including Festuca, Lolium and Poa species, field crops, including Zea, Glycine and Vaccincum species and various tree species have all been successfully established on sludge amended mine soils. Stucky *et al.* (1980), Sopper and Seaker (1982), and Stucky and Bauer (1989) provide an excellent overview of the growth responses and potential for metal accumulation in various species used in revegetation. The remainder of this section will focus on tree species, with emphasis on loblolly pine *(Pinus taedd).*

Berry and Marx (1977) transplanted loblolly pine seedlings into microplots containing strip-mined kaolin spoil amended with sewage sludges. Sludge amendments equivalent to 34 mt/ha had greater height (49% increase), stem diameter (79% increase) and fresh weight (126% increase) than seedlings on non-amended soils. They found the percent of roots with ectomycorrhizae was higher on seedlings grown in spoil amended with sludge.

Berry (1985) planted loblolly pine in microplots amended with sludges of various ages and from different locales, and compared them to inorganic fertilized controls. Seedlings grown in aged sludges did not grow well, and were not as large as those growing in the controls. Poor growth was attributed to deficiencies of macronutrients, primarily nitrogen as 'fresh' sludges supported excellent growth. In assessing mycorrhizae relationships Berry contrasted his earlier work in finding *Pisolithus tinctorius* did not form ectomycorrhizae on seedlings grown with the sludges as well as on the seedlings grown with inorganic fertilizer. *Thelephora terrestris* formed ecotmycorrhizae equally well on both sludge and inorganic fertilizer treatments.

McNab and Berry (1985) assessed the distribution of above-ground biomass in loblolly, short leaf *(Pinus echinata)* and Virginia *(Pinus virginiana)* pines in a sludge and inorganic fertilizer amended copper basin in Tennessee. On plots amended with sewage sludge, Virginia pine produced significantly more total tree biomass than other species. Trees growing on sludge amended plots averaged 8 percent more wood as a percentage of total tree weight and proportionately less foliage than trees on plots amended with inorganic fertilizer. Estimates of stand biomass by regression was more than three times greater on the sludge plots than on fertilizer plots.

Moss *et al.* (1989) assessed the benefits of adding municipal sewage sludge, sawdust and inorganic fertilizer to surface-mined coal mine soil. Stem volumes of pitch x loblolly *(Pinus rigida* x *taeda)* were found to be five times larger in soils amended with sawdust plus 336 kg/ha slow release nitrogen, and three times larger in soils amended with 22 mt/ha sludge than fertilized only seedlings. Soil moisture retention was two times higher in sawdust amended soils than in all other treatments and was thought to be the largest factor in contributing to increased seedling growth.

Very little is known surrounding metal uptake by trees. Tree species (both coniferous and deciduous) tend to accumulate Cu, Zn and Cd in their roots as opposed to foliage, however in some hardwoods (silver maple, green ash) Cd was consistently higher in foliage (Morin 1981). Roth *et al.* (1982) postulates that tree species can tolerate abnormally high metal concentrations by changing the metals into forms not mobile within the plant. Long term impacts of sludges high in metal concentrations on biogeochemical cycling is unknown. Metals may inhibit soil microbial activity, slowing decomposition and nutrient availability (Roth *et al.* 1982). Morin (1981) states that tree species are useful in rehabilitation projects because they are not a significant food source, and due to their stature tend to retain heavy metals on the site in plant tissue not grazed by herbivores, reducing the potential for entry into the food chain.

NUTRIFOR FOREST FERTILIZATION RESEARCH PROGRAM

Building on the 18 years of research conducted by University of Washington and Seattle Metro on sludge application to forested land, the University of British Columbia and the Greater Vancouver Regional District have undertaken to initiate a. large four-phase research program to assess the degree to which the results from these previous studies are applicable to the areas of southwestern British Columbia. Research at University of Washington's Pack Forest has demonstrated that anaerobically digested municipal sewage sludge acts as an excellent slow release organic forest fertilizer (Henry & Cole 1986). Spectacular growth responses have been demonstrated on low productivity sites without unacceptable environmental impacts (Chapnum-King *et al* 1986). It is the intent of the NUTRIFOR program to develop a set of ecologically-sound guidelines for the environmentally-safe and economically-viable use of the sludge resource! to increase the growth of nutrient limited forests.

Each phase of this intensive research program involves a multi-disciplinary team of scientists and graduate students assessing human health concerns, effects on soil biology and chemistry, humus decomposition, stream water chemistry, tree jgrowth and physiology, vegetative community dynamics and forest fauna. The first phase, initiated in 1989, encompasses 42 small 10 X 10 m plots spanning three cutblock ages and two hygrotopes. An ancillary sludge fertilization rate trial is included. Each plot is intensively instrumented with suction cup lysimeters and ion exchange resin bags. Trees are measured yearly and foliar nutrient chemistry assessed. Movement of sludge (NUTRIFOR) constituents down into the soil profile are quantified. The potential for off-site movement is characterized. Potential impact on stream water chemistry is monitored. Trace metal uptake in tree seedlings and minor vegetation is delineated. The first phase involves a detailed process based approach to the potential impacts of sludge fertilization on forest land. The second phase, initiated in 1990, involves larger sub-operational plots in an ecosystem level approach. Again, potential changes in stream water and soil chemistry are assessed. The possible influences sludge application may have on small mammals is detailed. Human health concerns, including possible Giardia transmission is quantified. The third phase, initiated in 1990, involves a pilot study to assess organic waste mixes as slow release forest fertilizers. The organic wastes include combinations of sewage sludge, fish silage, fly-ash and wood waste. These combinations will be compared with conventional inorganic fertilizer and the "organic waste" alone. The fourth and final phase involves a large irrigation, sludge fertilization, inorganic fertilizer factorial experiment assessing tree physiological responses to water and nutrient additions in an attempt to delineate the relative importance of moisture and nutrition in limiting Douglas-fir growth. This final phase has just been initiated (May 1991).

A large data base has been constructed and the task of analysis for statistical significance is currently being undertaken. Stream water chemistry post application (Phase I, H) shows no appreciable impact of sludge applications. Increased growth of crop trees and minor vegetation is evident, and expected.

The applicability of the NUTRIFOR research program to mine reclamation utilizing sewage sludge is considerable. The development of an extensive monitoring program within the NUTRIFOR project provides a framework for the monitoring that would accompany an application to mine soils, albeit at a much lower frequency and intensity. Queries regarding the potential for trace metal uptake, effect on forest fauna and possible health risks may be quantified. Potential growth increases of tree species in response to sludge fertilization can be estimated. The largest role the NUTRIFOR program has in the development of a sludge/mine reclamation project is in the delineation of a monitoring program, development of suitable application technologies and identifying potential vegetation responses.

CONCLUSION

The major factors restricting vegetation development on mine soils are low pH, poor water-holding capacity, low N availability and high surface temperatures. Sewage sludges improve the water-holding capacity by adding organic matter, large quantities of nitrogen, increasing the pH and buffering capacity of the site and moderating extremes in soil temperature.

The use of anaerobically digested de-watered sewage sludge offers a capability for greatly increasing sludge offers a capability for greatly increasing the ease of revegetating mine soils, tailings and spoils. A single application, applied at an appropriate rate can be used successfully to facilitate revegetation to a permanent, self-sustaining vegetative community with minimal adverse effects on vegetation, soil and ground water. Tremendous growth responses can be seen with tree species on sludge amended mine soils.

Operational experience is available for handling systems, application systems and the response of various types of vegetation (eg. Younos 1983). The single most important logical factor in using sewage sludge for most reclamation sites is economic - the transportation costs involved in moving the sludge from the treatment facility to the mine site. Empty unit trains, returning to the mine site have been economically viable and used successfully in transporting sewage sludge to the mine site (Snyder 1982).

For additional information on the NUTRIFOR research program contact Dr. M. McDonald - Faculty of Forestry, U.B.C., Vancouver, B.C.

For additional information on utilizing sewage sludge in a mine reclamation facility contact Mr. C.C. Peddie - Greater Vancouver Regional District, Burnaby, B.C.

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