SEVEN YEARS OF RESEARCH ON RECLAMATION USING BIOSOLIDS AT HIGHLAND VALLEY COPPER

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ABSTRACT

A research program was initiated at the Highland Valley Copper mine near Logan Lake, B.C. in 1996 to test application of de-watered sludge from municipal wastewater treatment plants (biosolids) as a potential reclamation treatment and to assess environmental effects. Control treatments were included in the study design to compare biosolids application with standard reclamation treatments using annual application of chemical fertilizers during the first four to five years of vegetation establishment. The biosolids research program has included monitoring to assess changes to soil, soil water and vegetation chemistry, and effects on vegetation cover and biomass production on the treated sites. This paper presents the results to date, including findings on element mobility following biosolids application, and effects on vegetation chemistry and soil nutrient capital. The potential benefits and limitations of biosolids application in Highland Valley Copper's reclamation programs are summarized.

INTRODUCTION

Highland Valley Copper is one of the largest porphyry copper-molybdenum mines in North America, producing roughly 400 million pounds of copper and 3.6 million pounds of molybdenum annually. The mine site is located in the southern interior of British Columbia, 80 km southwest of Kamloops. To date, approximately 6100 ha have been disturbed through mining operations, with over 2000 ha revegetated. End land use objectives at the mine site include wildlife habitat and forage for livestock.

Typical reclamation treatments at the mine site include direct seeding and planting on waste rock and tailings materials. Where necessary, overburden (glacial till) materials are used for capping waste deposits that are either chemically or physically unsuitable for direct revegetation. However, the quantity of overburden for reclamation is limited due to coarse texture, high molybdenum concentrations, and a lack of salvage during initial mine development, and thus there are insufficient overburden materials available for capping all mine disturbances. Initial mine development at Highland Valley Copper occurred in a regulatory era in British Columbia when soil salvage and replacement was not a permit requirement or a routine component of operations and reclamation.

Due to the above conditions, reclamation of some non-capped waste materials at Highland Valley Copper is challenging, and potentially limited by the following waste material physical and chemical characteristics:

- low organic matter contents and nutrient concentrations;
- low soil water holding capacity due to high coarse fragment contents and/or coarse fine-fraction textures; and
- elevated metals concentrations (particularly molybdenum) that can result in increased vegetation uptake and limitations on suitability for grazing and potentially for wildlife end land uses.

On waste materials with adequate water holding capacity, self-sustaining vegetation has been established through seeding and planting, and 4-5 years of fertilizer applications. On materials with low water and nutrient holding capacities, vegetation has not been sustainable. This has been observed on coarse (cycloned) tailings areas, certain waste rock types resistant to weathering, and waste rock dumps that have been capped with overburden at either insufficient depth or with material having an excessively coarse texture. It was recognized that incorporation of organic matter into these waste materials could improve reclamation success. In 1996, Highland Valley Copper, along with the Greater Vancouver Regional District (GVRD), implemented a research program to test the potential use of treated de-watered sewage sludge (biosolids) as a reclamation treatment on the mine site. In 1998, operational application of biosolids commenced on reclamation areas. By the end of 2002, approximately 150,000 wet tonnes of biosolids had been applied to over 350 ha of the mine site.

METHODS

Replicated research trials were installed in 1996 and 1997 to test:

- two application methods – topdressing and incorporation;
- use on two waste materials – tailings and waste rock; and

- various application rates, in comparison to standard chemical fertilization treatments.

Topdressing trials were established to evaluate the effects of surface applications of biosolids at relatively low rates (25-50 dry tonnes [dt]/ha) onto areas that had been previously revegetated but had low productivity. Incorporated trials were established on unreclaimed areas (or areas where previous conventional reclamation had mixed success), testing higher rates (100-200 dt/ha) of biosolids tilled or ripped into waste materials using agricultural equipment or cat-mounted implements. Sites selected for trials were challenging reclamation sites where a 0.5 m till capping would have been prescribed to improve material conditions.

When considering effects of biosolids application, it is important to note that chemical composition of biosolids may vary widely due to differences in waste sources, and the type and length of digestion/treatment processes. Even within the GVRD system, biosolids chemistry varies by source treatment plant (treatments used in the GVRD system are generally anaerobic, mesophilic to thermophilic digestions with retention times of 20-40 days).

Annual monitoring of these trials since 1996 has included assessment of the effects of biosolids application on vegetation productivity, soil, soil water, and foliar chemistry. The following discussion will present results of this research program. For brevity, results of statistical analyses have not been included in this paper. However, in the following discussion, use of the term "significant" indicates statistically, as opposed to visually, identified trends or differences. Statistical tests used primarily include analyses of variance and repeated measures testing (α = 0.05).

RESULTS

For clarity in understanding the effects of biosolids application in this study, the following sections will present initial or short-term (2 to 3-year) results following biosolids application, and then examine longer-term (5 to 7-year) results available to date. Although the discussion primarily focuses on results from the tailings trials, these results are consistent with those observed on waste rock. It should also be noted that while these trials are concerned with forage production because of site-specific end land use objectives, biosolids treatments have also been used and evaluated on planted areas designed to provide post-closure wildlife habitat.

Initial Results

Effects on Vegetation Production: The biosolids applied in this trial had total nitrogen concentrations of approximately 2-4 percent, with a mean concentration of approximately 3.8 percent. Using this mean value, nitrogen loading rates for each application treatment are shown in Figure 1 – note that the value for the chemical fertilization treatment is the cumulative loading over five years of application. Nitrogen applied in chemical fertilizers is in the ammonium form; nitrogen applied in biosolids is approximately 35 percent ammonium, with the remainder in organic forms.

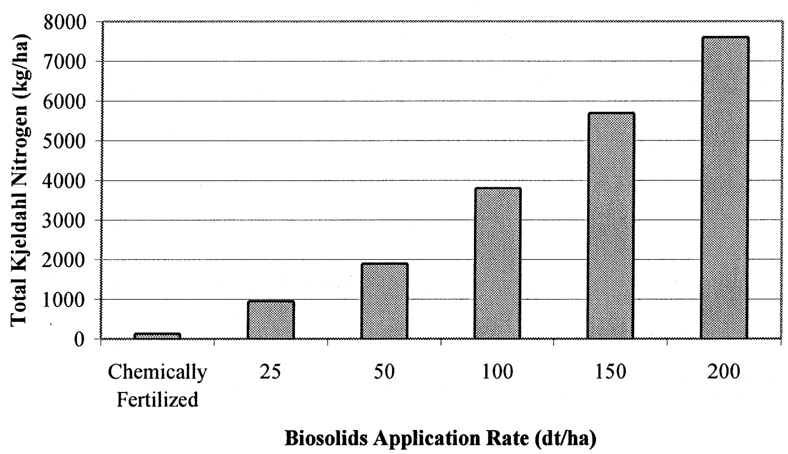

Figure 1 Total Nitrogen Applied by Treatment

Vegetation monitoring in this study shows that the high nitrogen applications in biosolids result in an initial (2-3 years after treatment) significant increase in above-ground biomass of forage crops compared to chemically fertilized treatments (Figure 2). These data indicate that early biomass production from biosolids application rates of 50 dt/ha and above are approximately 2.5 times higher than on the chemically fertilized treatments. On tailings sites, biosolids application also aids initial vegetation establishment by replacing surface emulsion treatments that reduce wind erosion of sands (through adhesion of

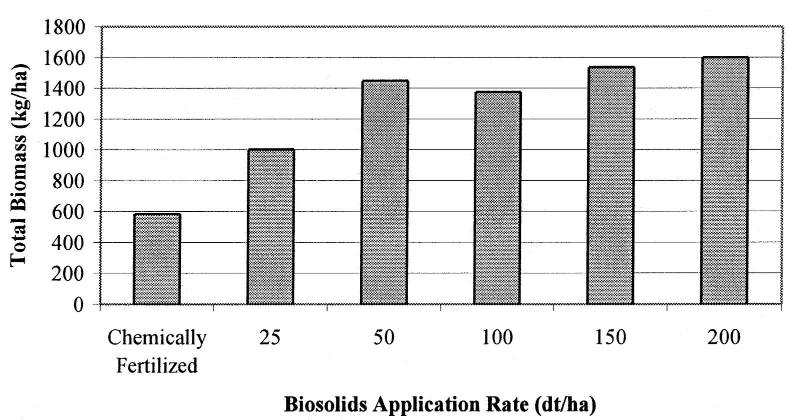

Figure 2 Total Forage Biomass by Treatment, 2-3 Years After Application

particles to biosolids or other agents), which can cause substantial mechanical damage to emergent seedlings if uncontrolled.

Effects on Elemental Concentrations and Mobility: Biosolids application results in increased loading to the soil system of elements contained primarily in organic molecules, such as nitrogen, phosphorus and sulphur, as well as metals such as copper, mercury and zinc, which originate from various waste sources. Monitoring of foliar and leachate chemistry on the biosolids trials at Highland Valley Copper indicates that the labile organic nitrogen and sulphur-containing pool is mineralized relatively rapidly, resulting in an increase in mobile forms of these elements. The kinetics of these processes result in a peak in foliar and leachate concentrations of nitrogen and sulphur within three years of application, and a return to pre-application levels within five years of treatment. Peak nitrate levels measured in leachate collected 2 m below surface reached 400 ppm on the 200-dt/ha treatments in the year following application. Whether such high-nitrate releases from application are acceptable depends on the receiving environment. In the case of Highland Valley Copper's tailings application, groundwater does not move towards the tailings pond, and has a minimum estimated residence time of two decades, as well as substantial dilution, prior to release at the dam base.

Sulphur release followed a similar pattern to that of nitrogen, with higher rates of biosolids application having significantly higher foliar sulphur concentrations than lower rates and chemically fertilized treatments. This was of particular interest at Highland Valley Copper due to elevated foliar molybdenum concentrations, and the role of thiomolybdates in inducing secondary copper deficiency (molybdenosis) in ruminants. Monitoring has shown that elevated foliar and leachate sulphur concentrations resulting from biosolids application are a short-term phenomenon, with peak concentrations observed four years after application, and decreasing concentrations observed thereafter.

Monitoring has shown no increase in foliar and leachate metal concentrations as a result of biosolids treatment. This finding indicates that metals applied in biosolids treatments remain immobilized, likely as a result of organic complexation. In addition, there is no evidence that copper, which is present at high concentrations in the mine waste materials, has been increasingly mobilized from these materials as a result of biosolids application. It should be noted that the pH of waste materials at Highland Valley Copper is generally neutral to slightly alkaline. As mobility of many metals is partially pH dependent, this has bearing on observations on metal mobility in this research. Application of biosolids on more acidic materials might not result in similar patterns of immobilization.

An effect that was unanticipated prior to commencement of biosolids research at Highland Valley Copper is that biosolids treatments decreased mobility of molybdenum in the rooting zone. Molybdenum is present in elevated concentrations in the mine waste materials, and can result in high foliar molybdenum concentrations and potential dietary problems in range cattle utilizing the site. Biosolids application has resulted in significant reduction in foliar molybdenum concentrations in comparison to chemical fertilization treatments (Figure 3). As with metals added in biosolids, the mechanism for reduced molybdenum mobility following biosolids application is likely primarily increased molybdenum adsorption to biosolids-related organic matter. Research on longer-term dynamics of biosolids decomposition indicates that reduced mobility as a result of organic complexation may persist for decades, due to slow long-term biosolids decomposition rates (Sloan *et al.*, 1998; Prescott and Brown, 1998; and Granato *et al.*, 1999).

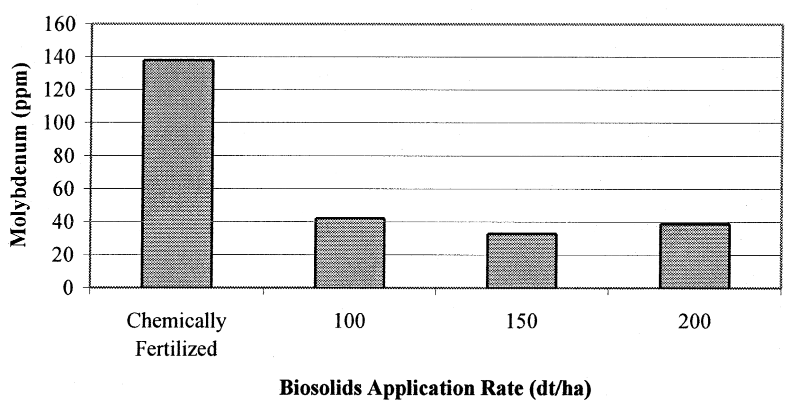

Figure 3 Alfalfa Foliar Molybdenum Concentrations by Treatment

Effects on Soil Available Water Holding Capacity: One of the beneficial properties that is generically attributed to soil organic matter is its ability to increase soil available water holding capacity, or the water content that a given soil material is capable of holding between field capacity (commonly defined as 10 kPa of tension for coarse-textured soils) and permanent wilting point (1500 kPa). Available water holding capacity is highly dependent on particle size. Organic matter generally has a higher water content at a given tension than mineral materials; however, for colloidal or humus-like organic substances, water contents at field capacity and permanent wilting point tend to be equally higher in proportion than in mineral materials. Thus, many sources have reported an increase in soil moisture content with increasing organic matter at both field capacity and permanent wilting point, and thus no change in AWSC, particularly when volumetric (as opposed to gravimetric) water content is considered (Moskal *et al*., 2001, and Zebarth *et al*., 1999).

This relationship is illustrated in Figure 4, which shows water retention curves for different materials on the Highland Valley Copper tailings biosolids research sites. Materials included in this figure are "beach" sands, or complete tails (sand with approximately 8% silt and 4% clay); "dam" sands, or cycloned sands, composed entirely of coarse sand particles; standard biosolids; and "land-dried" biosolids from the GVRD Iona plant, which are composed of approximately 8% organic matter (biosolids) in a sandy-loam mineral material. Treatments on the "dam" materials included an area of standard (Annacis) biosolids incorporated at 150 dt/ha in 2001, and an adjacent control that received chemical fertilizer in 1996-1999. On the beach site, treatments included an area of "land-dried" Iona biosolids incorporated at 403 dt/ha in 2001, and an adjacent control that received chemical fertilizer in 1996-2000.

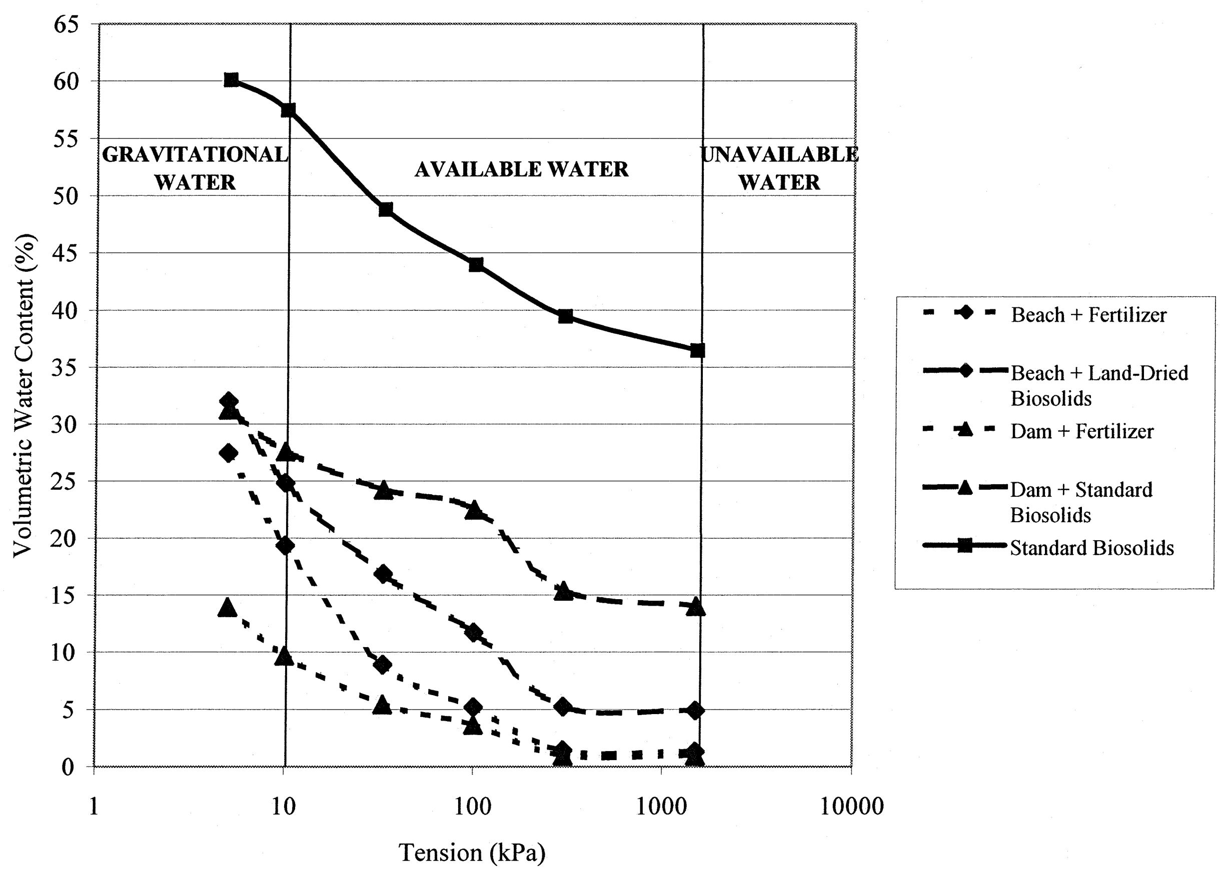

Figure 4 Available Water Holding Capacity by Treatment

Figure 4 shows mean water retention curves for the four treatments, plus a curve for unmixed Annacis biosolids. Vertical lines on the graph mark the tensions for field capacity and permanent wilting point, with the zone of water availability between these lines. Although the field capacity line is indicated at 10 kPa due to the coarse texture of the sand and sand-biosolids mixes, in considering unmixed biosolids, a tension of 33 kPa should be used for field capacity, as this is more appropriate for fine-textured or organic materials. To evaluate the effects of biosolids application on similar materials in Figure 4, the dashed lines with points delineated by triangles should be compared to each other for dam sands, and the lines with points delineated by diamonds should be compared to each other for beach sands. A comparison between the mineral materials (unmixed tails) is provided by the two lowest lines on the graph.

Analysis of the available water holding capacity results in this study indicates a significant effect of materials, with the finer-textured beach materials having roughly twice the available water holding capacity of the cycloned dam sands (Table 1). This is reflected in Figure 4, where lines representing beach material have a steeper slope between tensions of 10 and 300 kPa than those of dam materials. Analysis also shows a significant effect of standard biosolids application on the cycloned dam sands, but no significant effect of land-dried biosolids application on the beach. This is due to the fact that the available water retention of the unmixed standard biosolids exceeds the very low retention value for cycloned sand, and thus the mixture results in improvement in retention. On the beach, on sands with finer particle sizes and a larger silt and clay component, there is no statistically discernible improvement following land-dried biosolids application. Again, this is reflected in the beach lines in Figure 4, which show proportionately greater water retention with biosolids addition at both field capacity and permanent wilting point, and thus no improvement in available water. In this case, addition of biosolids has merely shifted the beach + biosolids line upward roughly equally at all points, in comparison to the beach + fertilizer line. Note that despite the improvement in cycloned sand water retention characteristics following biosolids application, retention on this material is still below that of unamended complete tails, and revegetation success on this treatment has been limited. These results indicate that on materials that are comparable or finer to complete tails, biosolids application produces little change in available water holding capacity. On poorer materials, biosolids application may improve this capacity, but not enough to eliminate the substantial soil moisture limitations to successful reclamationon these sites.

Table 1 Soil Available Water Holding Capacity (% by volume) by Treatment on Tailings		
	Fertilization Method	
Material	Chemical	Biosolids
Beach	18	19.9
Dam	8.7	13.6

Longer-Term Results

Before discussing longer-term results, it is important to note again that the trials in this study were installed on materials with poor physical properties where conventional reclamation techniques had proven unsuccessful, and where capping with more suitable materials had been prescribed. As noted above, these sites have substantial soil moisture limitations to reclamation, which the water holding capacity research in this study indicates are not removed through biosolids application.

Effects on Vegetation Production: Forage production results for the tailings trials are presented in Figure 5. These data indicate that the earlier production peaks generated by biosolids application have not been sustained over the longer term. Six years after treatment, there is no difference in production levels between application rates of 50-200 dt/ha, with these levels less than a third of those attained at the peak, and substantially below levels measured on better materials on the mine site (see Jones *et al.*, this volume).

Another illustration of the effects of biosolids application on challenging sites is provided by vegetation production data from reclaimed waste rock from Lornex Southeast. This site was originally reclaimed using conventional fertilization methods in 1990. Although it initially responded well to chemical fertilizer, grass biomass steadily declined following establishment, and declined rapidly after withdrawal of maintenance fertilizer applications. By 1997, vegetation performance was judged to be inadequate, and the site was re-treated with biosolids incorporation. Figure 6 shows biomass production over time for the initial fertilizer and subsequent biosolids treatments on this site.

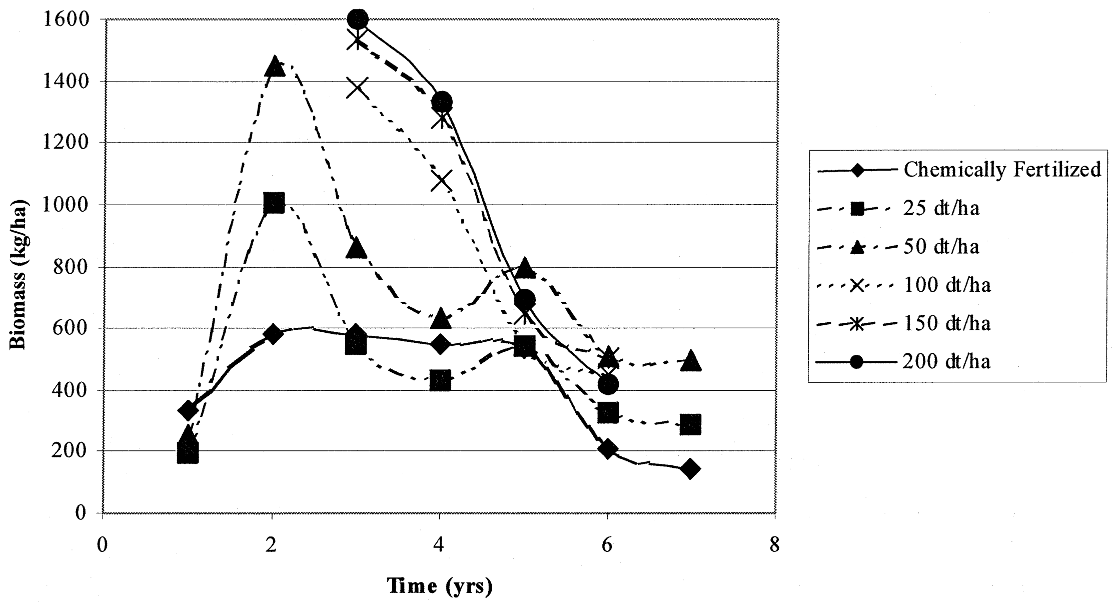

Figure 5 Biomass Production by Treatment over Time

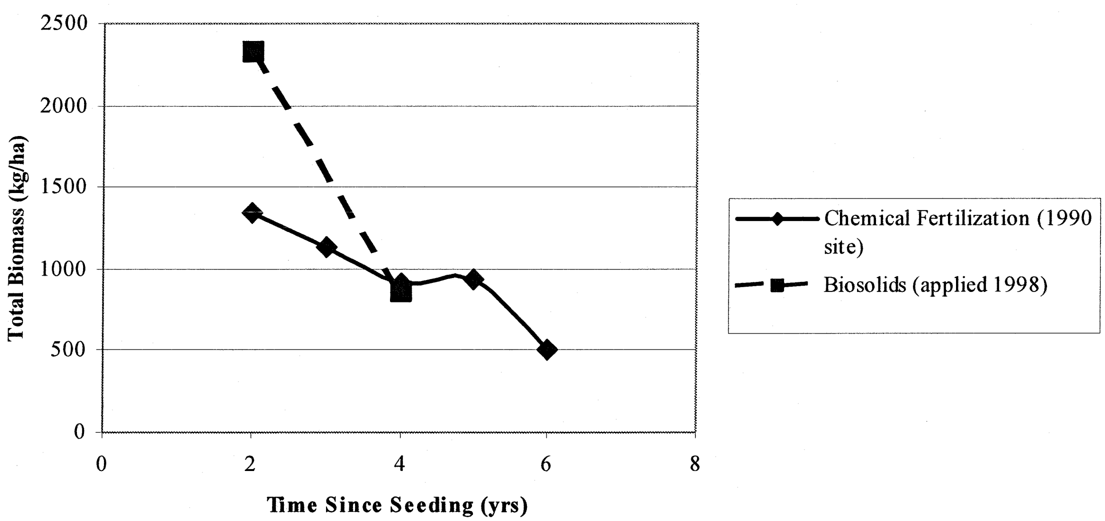

Figure 6 Biomass by Treatment on Lornex Southeast

The date presented in Figure 6 show a similar trend parallel to that observed on the research plot trials. Total biomass on the incorporated biosolids treatment initially exceeds that produced by chemical fertilization, likely due to higher nitrogen delivery, but both treatments converge on similar levels following the initial flush of mineralized nitrogen.

The purpose of examining the biomass data is not to determine whether biosolids can be successfully used in reclamation at Highland Valley Copper, as experience with conventional fertilization demonstrates that given an understanding of both waste material and amendment limitations, reclamation using biosolids will be successful and sustainable. Rather, the primary value of the trial results is in defining the limitations of biosolids treatments, and thus in identifying conditions for their optimal use.

Available water holding capacity research in this study suggested that long-term results of biosolids application on the trial sites would not be favourable, as these sites have substantial moisture limitations to successful reclamation, which are not adequately amended through biosolids treatment alone. Given this conclusion, it is interesting that biosolids application produced an initial substantial response in vegetation production, despite unaddressed soil moisture limitations. A possible explanation is in the different species groups in the forage stands on these sites and the growth requirements of these groups. The forage stands are composed of grasses (primarily *Festuca* and *Agropyron* spp.) and legumes (primarily *Medicago sativa*). Despite moisture limitations, grass growth on these sites is primarily nitrogen-limited, as seeded species are drought-tolerant, but dependent on available soil nitrogen for nutrition. The agronomic legumes seeded on these sites are primarily moisture-limited, as they have the capacity for symbiotic nitrogen fixation, but are less drought-tolerant than grasses. An examination of the components of biomass indicates that grass species account for almost all of the measured response to treatment on the trial sites, with a large increase immediately following application and a subsequent decline. Legumes remain a small and stable stand component. This is illustrated by the biomass components for different treatments at the Lornex Southeast site two years after seeding (Figure 7).

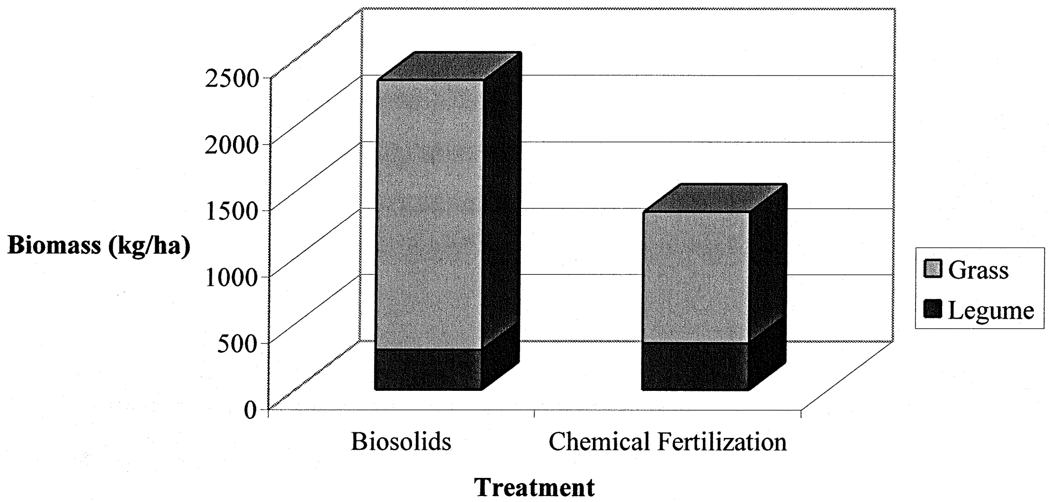

Figure 7 Biomass Components by Treatment at Lornex Southeast

These data support the hypothesis that on high coarse fragment-content or coarse-textured sites, forage production is nitrogen-limited for grasses and moisture-limited for legumes.

If legume production has not been increased by biosolids applications on these sites due to soil moisture limitations, and grass production is increased as a result of nitrogen additions, then why is grass production not sustained over a longer period, given the amount of organic nitrogen added in biosolids applications? The soil chemistry data show that substantial total nitrogen capital (approximately 1500-3000 kg/ha) remains five years after biosolids application, when production levels have dropped significantly. However, soil mineral nitrogen data indicate that nitrogen mineralization rates from biosolids are high for 2-3 years following application, and then decrease to very low rates. These longer-term release rates appear too low to sustain grass biomass production on a coarse-textured site with low nutrient retention capacity. (Note that decomposition processes on these sites are also moisture-limited, and thus retarded in comparison to sites with better soil moisture conditions.) Other studies on the effects of biosolids application on plant growth have indicated similar findings (Prescott and Brown, 1998). This work suggests that there may be different pools of nitrogen in biosolids: a labile, rapidly mineralized pool (10-50 percent of organic nitrogen in biosolids; generally in the lower range in anaerobically digested materials), and a non-structural or humus-like recalcitrant pool that may be more resistant to decomposition than native soil organic matter (Rowell *et* al., 2001). This latter pool releases mineral nitrogen so slowly that it may be inconsequential as a fertilization source.

CONCLUSIONS

The biosolids research program at Highland Valley Copper has produced the following conclusions regarding the use of biosolids in reclamation of challenging mine waste materials at this site:

1. Biosolids are a high-nitrogen organic fertilizer, and can be effectively used in mine reclamation programs. Use of biosolids can provide benefits to both industrial operators and municipal governments by simultaneously providing a nutrient source to nutrient-poor waste materials, and recycling wastewater treatment products.
2. Despite often-voiced concerns regarding metals additions from biosolids, this study has shown no mobility of metals originating from biosolids. Conversely, biosolids application has resulted in immobilization of elements found in mine waste materials, and thus in improved forage quality.
3. Biosolids application is not a substitute for adequate surface material physical properties. Material characteristics determine reclamation success, and reclamation with biosolids is governed by these characteristics to the same extent as conventional fertilizer use.
4. Biosolids in this and other studies have released mineral nitrogen rapidly for only 2-3 years after application. Subsequent to this period, remaining organic forms appear to be recalcitrant humus-like materials that contribute little to site fertilization, particularly on coarse-textured, moisture-limited sites. Although these remaining materials may supply nutrients over the long term, they may have no positive effect on short and medium-term biomass production.

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REFERENCES

Granato, T., Pietz, R., Knafl, G., Carlson, C., Tata, P. and Lue-Hing, C. 1999. Effect of time after cessation of biosolids applications on the concentrations of cadmium, copper, nickel, and zinc in soil, leaves, and grain of corn. Report No. 99-23. Metropolitan Water Reclamation District of Greater Chicago.

Moskal, T.D., Leskiw, L., Naeth, M.A. and Chanasyk, D.S.. 2001. Effect of organic carbon (peat) on moisture retention of peat : mineral mixes. Canadian Journal of Soil Science. Volume 81 No.2: 205-211.

Prescott, C. and Brown, S. 1998. Five-year growth response of western red cedar, western hemlock, and amabilis fir to chemical and organic fertilizers. Can. J. For. Res. 28: 1328-1334.

Rowell, D., Prescott, C. and Preston, C. 2001. Decomposition and nitrogen mineralization from biosolids and other organic materials: relationship with initial chemistry. J. Environ. Qual. 30: 1401-1410.

Sloan, J., Dowdy, R. and Dolan, M. 1998. Recovery of biosolids-applied heavy metals sixteen years after application. J Environ. Qual. 27: 1312-1317.

Zebarth, B., Neilsen, G., Hogue, E. and Neilsen, D. 1999. Influence of organic waste amendments on selected soil physical and chemical properties. Can. J. Soil Sci. 79: 501-504