RECLAMATION OF ACIDIC COPPER MINE TAILINGS USING MUNICIPAL BIOSOLIDS[1]

by

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Abstract: Reclamation of copper mine tailings in a cost effective, successful, and sustainable manner is an ongoing area of evaluation in the arid southwest. A study was initiated in September, 1996 near Hayden, Arizona to evaluate the use of municipal biosolids for reclaiming acidic copper mine tailings (pH of 2.5 to 4.0). The main objectives of the study were to 1) define an appropriate level of biosolids application for optimum plant growth, and 2) evaluate the effects of green waste and lime amendments. The experiment was a randomized complete block design with four biosolid rates of 20, 70, 100 and 135 dry tons/acre (45, 157, 224, 303 Mg/ha), three amendment treatments (none, green waste, and green waste plus lime); with three replications. Non-replicated controls (no treatment, green waste only and lime only) were included for comparison. Shortly after biosolids incorporation to a depth of 10-12 inches (25.4-30.5 cm), composite soil samples (0-12 inches) of each plot were taken. Biosolids incorporation increased the pH of the tailings (>5.75) and additional increases in pH were noted with lime application. In January 1997, the plots were seeded and sprinkler irrigation was commenced. A total of 4.47 inches (11.4 cm) of rainfall and 3.8 inches (9.7 cm) of irrigation were applied until harvest in May 1997. Data from the first growing season indicates optimum growth (>66 lbs/acre or >74 kg/ha) at biosolids rates of 70-100 dry tons/acre. There was a significant positive effect on growth of green waste and lime amendments. Surface NO_3-N concentrations in biosolids amended plots were greatly reduced (from 23 to 6 mg/kg) by addition of green waste. There was no evidence for NO_3-N leaching below 12 inches (30.5 cm).

Additional Key Words: Arid southwest, sewage sludge.

Introduction

The use of municipal biosolids for land reclamation has been researched extensively during the last twenty years. As of 1993, approximately 72 sites in the United States had been reclaimed using biosolids (Sopper, 1993). However, the majority of these sites are located in the coal mining region of Pennsylvania. Limited research has been conducted in the western U.S., on only three sites in Colorado, one in New Mexico, and one in Washington. Previous research has shown that biosolids may increase pH, improve water holding capacity and infiltration, decrease bulk density, and reduce surface temperature (Sopper 1993). Research projects in Washington (McDonald and Shirts 1978) and British Columbia (Wilson et al., 1993) have focused on reclamation of copper mine tailings, but more research is needed on reclamation of acidic copper mine tailings in the arid Southwest.

The Southwest presents unique problems for reclamation because of high evapotranspiration rates, limited rainfall, and extreme summer temperatures. The use of biosolids for reclamation in the arid Southwest can be highly beneficial to the environment by aiding in the reclamation of land disturbed by mining and providing a method of disposal for municipal sewage sludge.

Current Arizona regulations limit the amount of class "B" (non-limed) biosolids applied to reclamation sites. The restrictions exist due to

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concerns regarding N leaching and include: limiting the application rate to five times the agronomic rate of N application over a five-year period and no application to tailings with pH <6.5 (Arizona Administrative Register 1996). Allowances were made by Arizona Department of Environmental Quality (ADEQ) for this research project to proceed with land application of biosolids to acidic tailings at rates well above those currently in rule. Significant revisions in the regulation of biosolids use for land reclamation will be necessary for large-scale projects. ASARCO Incorporated (Asarco) is working in cooperation with ADEQ and Pima County Wastewater Management (PCWWM) to revise the regulations for use of biosolids for reclamation of tailings.

Research was recently initiated on copper mine tailings near Hayden, AZ. The primary objectives of this research were to 1) determine the optimum rate of biosolids application for maximum plant productivity and minimal environmental contamination, 2) determine the need for green waste and lime amendments, and 3) determine effects of biosolids rate and amendments on: biomass production, plant cover, plant nutrient uptake, available metals in tailings, fate of nitrogen, and pH of tailings.

Methods and Materials

In early September 1996, experimental plots were established on copper mine tailings near the town of Hayden, Arizona (approximately 60 miles north of Tucson). The pyritic tailings were deposited at the site approximately forty years ago from the Hayden mill and smelter, then owned by Kennecott. The tailings are acidic (pH of 2.5-4.0) and have a very-fine sand or silty texture. The site is in a thermic temperature regime and an aridic moisture regime with an average annual rainfall of 12.5 inches (31.75 cm) during the past 70 years (Asarco-Hayden Engineering record, unpublished).

The experiment was a randomized complete block factorial experiment with a split plot design. The main plots consisted of four biosolids application rates of 20, 70, 100, 135 dry tons/acre (45, 157, 224, 303 Mg/ha), and the subplot treatments were three amendment treatments (none, green waste, green waste plus lime). There were three replications of each of the twelve treatments. The experiment also included three non-replicated control plots (no amendment, green waste only, lime only). There were a total of 39 plots, each covering 1800 ft^2 (167 m^2).

Laboratory measurements of N loss were performed to estimate the probable volatilization of N from the biosolids. A 50% N loss from the biosolids was measured after 48 hours exposure to the atmosphere (T. Thompson, unpublished). Therefore, the biosolids applied were assumed to contain 3% N (dry weight basis, Table 1).

Table 1. Nitrogen (N) and carbon (C) application rates. Biosolids contained 3% N.

Biosolids Rate	C Applied	N Applied
Tons/acre	lb/acre (kg/ ha)	lb/acre (kg /ha)
20	20,000 (22,417)	1200 (1345)
70	70,000 (78,458)	4200 (4708)
100	100,000 (112,083)	6000 (6725)
135	135,000 (151,312)	8100 (9079)

The N applied at the lowest rate of application (20 dry tons/acre, 1200 lbs N/acre) was approximately equivalent to five times the agronomic rate of N, the rate of application established by ADEQ. The other rates of application were approximately 17, 25, and 34 times the agronomic rate. Biosolids were delivered to the experimental test plots from the Pima County Wastewater Treatment facility located on Ina Road in Tucson, AZ. Loads were dumped on appropriate plots so approximately the correct amount could be applied on a weight basis (20-50% solids) and spread using a road grader and a front-end loader.

The green waste consisted of landscape wastes that were separated and ground (to 4 inch minus) at the Catalina landfill. Green waste was added to stimulate microbial immobilization of N. Rates of green waste application were calculated to result in a C:N ratio of >30:1 (approximately equivalent to biosolids application rates on a volume basis). Green waste was applied and spread on individual plots using a front-end loader and a road grader.

Lime ($CaCO_3$) application rates were based on the amount needed to neutralize 50% of the potential acidity to a 12 inch depth (16.5 tons/acre or 36.9 Mg/ha). The granular lime was obtained from the Hayden concentrator and was applied with a conventional fertilizer spreader. Amendment application order to the plots was green waste, lime, and biosolids. All amendments were incorporated simultaneously after surface application was completed.

Experimental plots were plowed in late December 1996 with a moldboard plow to a depth of approximately 12 inches. The spring season began January 2, 1997 with plot disking and broadcast application of seed (Table 2). Sprinkler irrigation was applied to the plots to supplement rainfall and to initiate germination of plant species. Unfortunately, the irrigation system was not operative until late February 1997, possibly limiting seed germination. In the spring season, a total of 4.47 inches (11.4 cm) of rainfall and 3.8 inches (9.7 cm) of irrigation was applied. The spring season irrigation was terminated in late May 1997.

Table 2. Seed mixes: spring and summer growing seasons

Season	Seed	% of total seed mix
Spring	Oats (*Avena sativa*)	26.4
	Winter Barley (*Hordeum volgare*)	25.2
	Streambank Wheatgrass (*Agropyson riparium*)	6.4
	Fourwing Saltbush (*Atriplex canescens*)	2.6
	Quail Bush (*Atriplex lentiformis*)	4.5
	Annual Ryegrass (*Lolium multiflorum*)	12.8
	White Sweet Clover (*Melilotus alba*)	9.0
	Yellow Sweet Clover (*Melilotus officinalis*)	13.2
	Total lbs (PLS) = 368.9	
Summer	Hulled Bermudagrass (*Cynodon dactylon*)	50
	Lehmanns Lovegrass (*Eragrostis lehmanniana*)	20
	Cochise Lovegrass (*Eragrostis lehman x atherstonii*)	10
	Alkali Sacaton (*Sporobolus airoides*)	20
	Total lbs (PLS) = 8.3	

Plots were tilled with a small rototiller in early June 1997 to begin the summer growing season. Each plot was tilled separately to prevent cross contamination between plots. The rototiller helped achieve improved mixing of the amendment for the summer season. Plots were seeded July 9, 1997 with perennial grasses (Table 2). In the summer season, 1.9 inches (4.8 cm) of rainfall and 9.5 inches (24.1 cm) of irrigation was applied. The summer growing season irrigation was terminated October 22, 1997. Surface evaporation was measured in both growing seasons (Table 3) using a watering gauge.

Table 3. Spring and Summer Season Irrigation, Precipitation (totals) and Surface Evaporation

Season	Irrigation	Precipitation	Evaporation
	Inches		
Spring (1/2/97–5/22/97)	3.8	4.47	57.8 (0.38/day)
Summer (7/7/97–10/22/97)	9.5	1.9	59.7 (0.69/day, 7/7– 9/30/97)

Sampling intervals were scheduled prior to experiment initiation. Composite surface samples (0-12 inches) were taken from each plot at the beginning of the spring growing season (January 3, 1997). Soil samples were analyzed for pH, metals (total and available), electrical conductivity, nitrate, total nitrogen, carbon and fecal coliforms. Composite surface samples (0-12 inches) were taken again in April and August, but were only analyzed for pH.

Nitrate leaching was monitored using ion-exchange resin capsules (Uni-best Inc., Bozeman, MT) placed at 4 foot depths below the surface via access tubes (Li et al, 1993, Wyland and Jackson, 1993). Resin capsules were originally placed at the site on January 8, 1997 and were removed for analysis at approximately one-month intervals thereafter. Resin extraction was accomplished using a KCl extraction technique developed specifically for this project (T. Thompson and M. Rogers, unpublished). In addition to ion-exchange resins, soil samples were taken from select plots (controls, 135 dry tons biosolids/acre plots with and without green waste) to depths of 4 feet once in each growing season. Nitrate and ammonium analyses were performed on samples at 1 foot depth intervals from a composite of three samples per plot.

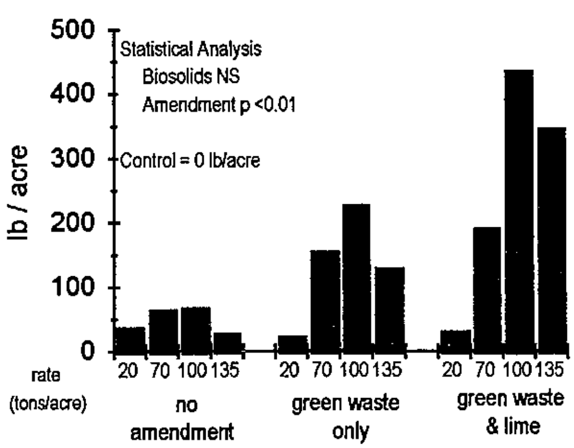
At the end of the first and second season, aboveground plant samples were collected to determine nutrient uptake and biomass production. Linear transects were made diagonally (corner to corner) in each plot. Aboveground plant samples were taken from a 1 ft^2 area at three-foot intervals along the transect. Sampling methodology was a composite technique based on harvest and line intercept methods (Chambers and Brown, 1983). Ocular density measurements were also taken on each plot (Soil Survey Staff, 1993).

Results and Discussion

Initial sampling of tailings with amendments (1/8/97) indicated little statistical difference in available metals with increasing biosolids application. There was a slight increase in available lead with additions of biosolids and other amendments. However, the highest concentrations of available lead were 2 ppm. According to research by Sopper, plant metal concentrations generally increase with biosolids application, but remain below phytotoxic concentrations and decrease over time (Sopper 1993). Similar research on copper mine tailings by Wilson et al. (1993) reported diluted levels of available copper with addition of biosolids. During the spring season (mid-March) chlorosis began to appear in some of the oat and barley vegetation in all treatments, and plants began to go dormant and/or die in late May. Analysis of plant tissue from the spring season indicated aluminum levels taken up by the plants that may have been phytotoxic. The plant samples were taken as composites, therefore the possible toxicity may have only occurred in certain species. It is also possible that tailings residue on the plants may have contaminated the samples, thereby giving inappropriately high values for aluminum.

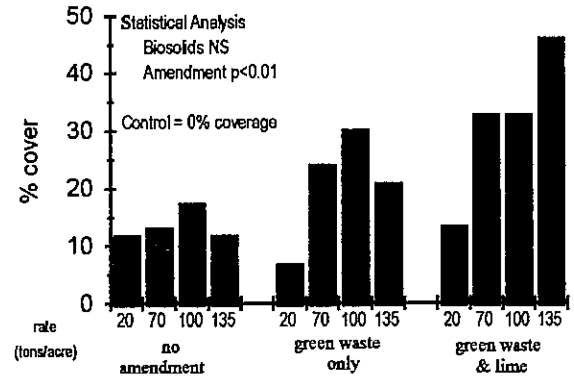
Spring season biomass production (Figure 1) indicates a positive effect of biosolids addition (>66 lbs/acre or >74 kg/ha at 70-100 dry tons biosolids/acre) and green waste and lime amendment (>400 lbs/acre or >448 kg/ha at 100 dry tons biosolids/acre). No plant biomass was present on the control plots. Biomass production on plots with a biosolids rate of 20 tons/acre was highly limited. Five times the agronomic rate of N

Figure 1. Average plant biomass production, spring season, (5/15/97)



application did not provide sufficient organic matter or plant nutrients for adequate vegetation establishment. Reduced growth occurred on plots with 135 dry tons biosolids/acre, possibly due to poor mixing with tailings. Estimates of plant cover (Figure 2) were taken prior to gathering plant biomass samples. The estimates are highly correlated to biomass production

Figure 2. Average estimated plant cover, spring season (4/23/97)



results. During the spring season most of the species seeded produced some amount of growth. The Sweet Clover (*Melilotus alba* and *Melilotus officinalis*) germinated first. Oats (*Avena sativa*), barley (*Hordeum volgare*), and ryegrass (*Lolium multiflorum*) also grew quite well.

Biomass production results from the summer season (Figure 3) were similar to those from the spring growing season, with a significant increase in growth resulting from biosolids addition (>2500 lb/acre or >2802 kg/ha at 100 dry tons/acre biosolids), but with no significant effect due to amendments. Summer season plant cover estimates (Figure 4) showed little

Figure 3. Average plant biomass production, summer season (10/7/97)

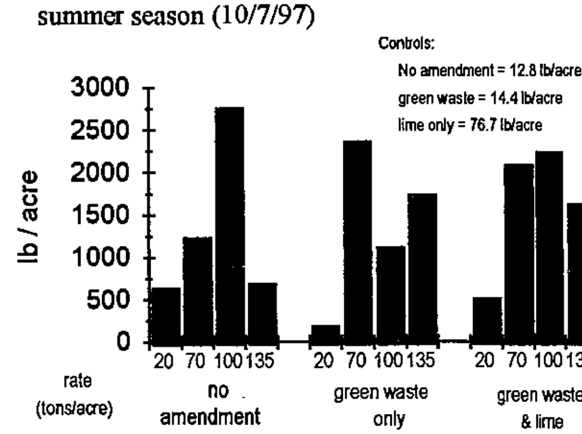


Figure 4. Average estimated plant cover, summer season (10/7/97)

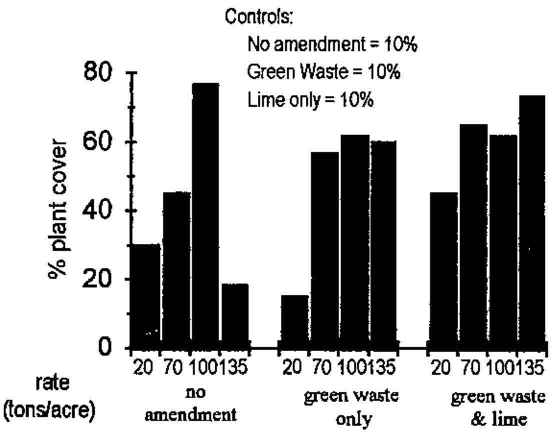
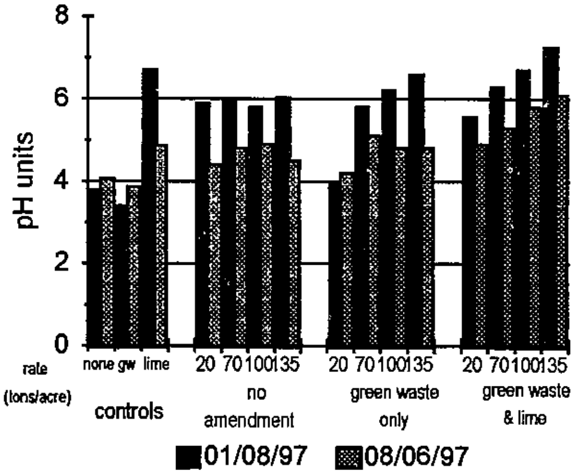


Figure 5. Average pH

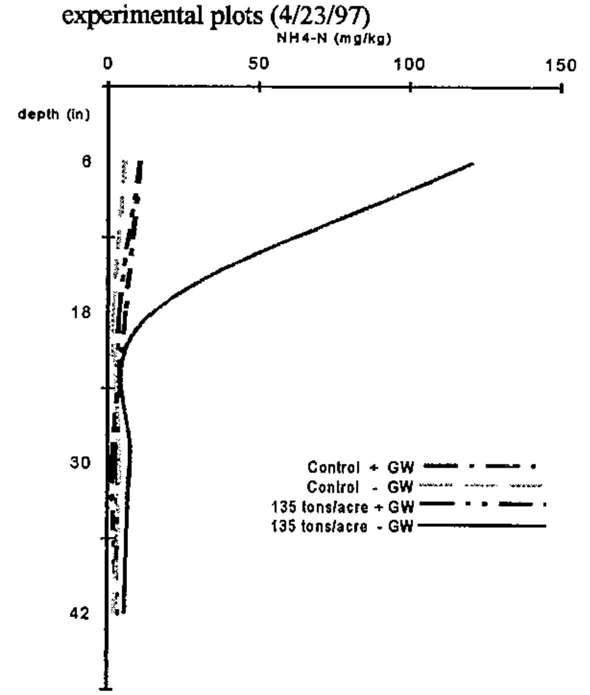


growth on control plots (10%), increased cover with biosolids amendment, and no significant benefit of green waste and lime additions. Green waste provided an excellent source of native species in the summer season. Mesquite (*Prosopis juliflora*), acacia (*Acacia* subfamily), mexican palo verde (*Parkinsonia aculeata*) and blue palo verde (*Cercidium floridum*), date palm (*Phoenix* species) and morning glory (*Ipomoea* species) grew on most green waste amended plots. The predominant species in the summer season was Bermudagrass. Bermudagrass is extremely hardy, which may account for improved biomass production in the summer season. Improved growth response in the summer season may also be the result of initial, daily irrigation to promote seed germination, better incorporation and mixing of amendments into tailings, and possible increase in available nitrogen.

Typical Arizona requirements for land application of biosolids mandate a substrate pH of >6.5 (Arizona Administrative Register, 1996). Control plot pH was <4 with no amendment and increased to >6 with addition of lime (1/3/97). Analysis of pH was performed in January, April, and August. Comparison of pH between project initiation in January and August 1997 (Figure 5) indicates a general pH decrease over time. Generally, biosolids alone had a slight effect on increasing pH. However, after seven months pH dropped to near control levels (4.0-5.0). As expected, addition of lime improved pH, but lime did not maintain pH levels above 6.5. The benefit of lime for increasing pH is limited, because acid generation occurs as pyritic mine tailings oxidize.

Analysis of ammonium and nitrate in the tailings indicated no substantial levels of leaching past 12-18 inches (30.5-45.7 cm). During the spring and summer seasons, select plots were sampled to 4 foot depths and analyzed for NO_3-N and NH_4-N. Results from the spring season show an increased level of NH_4-N (Figure 6) and NO_3-N (Figure 7) at the surface on plots with the highest rate of biosolids application and no green waste amendment. Green waste apparently did promote microbial N immobilization, and slowed the mineralization of organic N, but did not make a difference in leaching. Similar studies on copper

Figure 6. NH_4-N concentrations (mg/kg) with depth in selected Ray mine tailings biosolids experimental plots (4/23/97)



tailings indicate no NO_3-N leaching below 12 inches after one year (Wilson, 1993). Analysis of samples from the summer season again show increased NH_4-N (Figure 8) and NO_3-N (Figure 9) at the surface of plots with the highest rate of biosolids application with or without green waste. It should be noted that there were extremely low concentrations of NH_4-N and NO_3-N present in control plots. Most likely, the increased NO_3-N level is due to the increased mineralization of organic N to NH_4-N and further nitrification to NO_3-N. There is currently no evidence for significant amounts of NO_3-N leaching below 12-18 inches. However, further monitoring of NO_3-N may be warranted. Analysis of resins substantiate soil sample results, indicating no significant amount of NO_3-N leached to 4 feet (data not shown).

Conclusions

Overall, the use of biosolids for reclamation of acidic copper mine tailings on this site appears to offer promise for establishing a growth medium for plants. Plant biomass results indicate a significant positive effect of biosolids at rates of 70 to 100 dry tons/acre. Biosolids rates of 20 dry tons/acre and above 100 dry tons/acre may limit plant response and tend to be difficult to spread uniformly. However, new technologies for application may improve uniformity of distribution.

Green waste and lime amendment improved growth in the spring season, but not in the summer growing season. Green waste also promoted immobilization of N in the spring season. Using green waste from a local landfill may also help to establish native species into the reclamation project without seeding. The coarse texture of the green waste used in this study proved to be difficult to incorporate, but did have benefits (improved C:N, introduction of native species). Lime improves pH and possibly plant response over the short term, but this may not be sustainable.

It appears that 70-100 dry tons biosolids/acre provides a valuable source of organic matter to the tailings and nutrients for plants. Higher rates of biosolids amendment have shown no NO_3-N leaching below 12-18 inches and no significant increase in available metals. The use of biosolids for reclamation of acidic copper mine tailings in the arid southwest may be a viable alternative to some conventional reclamation techniques. Use of biosolids and green waste for reclamation reduces the amount of waste that must be landfilled or disposed of in some other

Figure 8. NH_4-N concentrations (mg/kg) with depth in selected Ray mine tailings biosolids experimental plots (8/1/97)

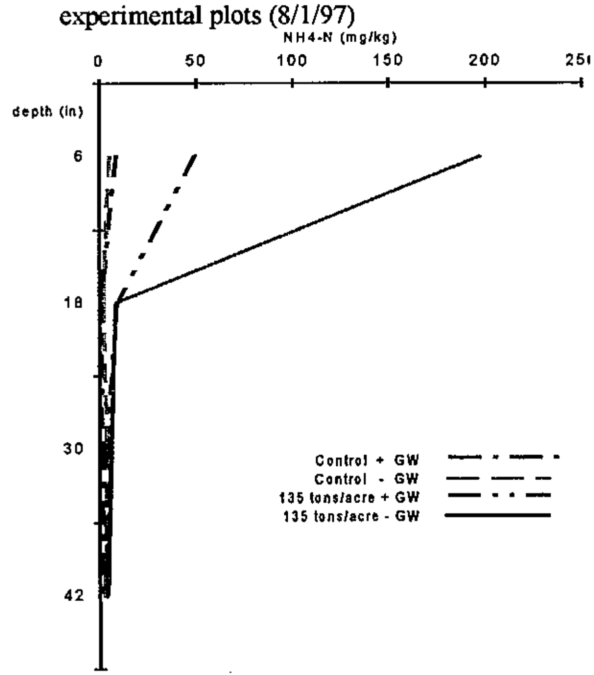
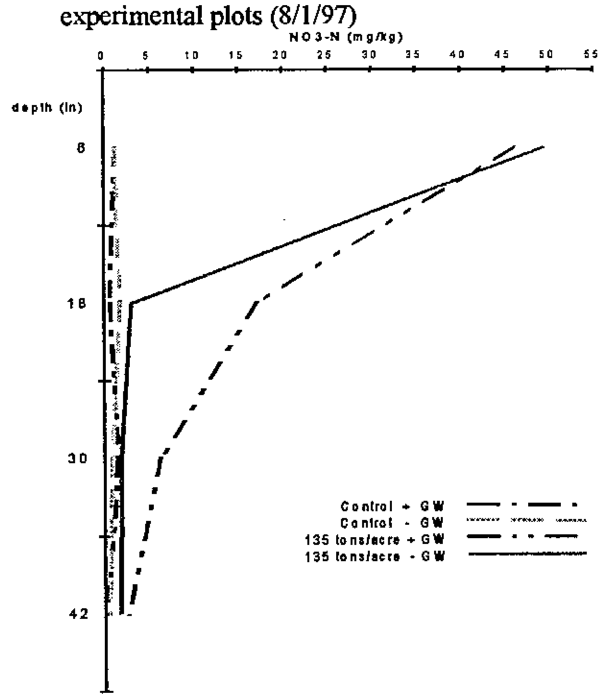


Figure 9. NO_3-N concentrations (mg/kg) with depth in selected Ray mine tailings biosolids experimental plots (8/1/97)



manner, and can prove to be economically feasible and beneficial to mining companies and municipalities.

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