2000 Billings Land Reclamation Symposium

SOIL AND WATER QUALITY ASSOCIATED WITH LAND APPLICATION OF BIOSOLIDS FOR SURFACE MINE RECLAMATION: FOUR CASE STUDIES

T. E. Herlihy, K. L. Hoover, and T. A. Rightnour

ABSTRACT

Land application of biosolids (municipal and industrial wastewater treatment plant solids) was employed as a beneficial-use soil amendment for reclamation of four surface coal mines in Pennsylvania. Soil and water quality data collected for regulatory reporting before, during, and after biosolids application were analyzed to assess the effects of application on site soils and surrounding receiving water points. The number of background water samples included in the regulatory sampling program was found to be insufficient to make comparisons between pre- and post-application water quality conditions. Soil sampling data from the biosolids application areas indicate that phosphate levels are relatively constant for the first four years following application, while potash and magnesium levels decrease by approximately 15 percent per year, and cation exchange capacity decreases by approximately 9 percent per year. Although declining trends were observed for the latter parameters, post-application levels of all four parameters were significantly higher than pre-application levels, and the addition of biosolids to severely disturbed soils benefits soil quality in the short term and promotes long-term improvements in soil fertility. Additional data not included in the regulatory monitoring program for these sites would be required to fully evaluate the success of biosolids application with regards to water and soil quality.

Current Contact Information: Water's Edge Hydrology, Inc. P.O. Box 868, Clearfield, PA, 16830. 814-592-2216. trightnour@wehydro.com or khoover@wehydro.com – http://wehydro.com

INTRODUCTION

Restoration of acceptable vegetative cover on reclaimed mine lands can be difficult because post-mining soils often have a less developed soil structure and reduced organic matter and plant-available nutrient contents than the original in-situ soils. Bulk stripping of soil tends to mix organic topsoil and mineral subsoil horizons, resulting in a new media on which it can be difficult to establish and maintain vegetative cover. Segregation of soil horizons during site clearing and replacement of horizons in their original order is impractical, and it is still inevitable that productive soil structure and properties will be lost. Additionally, on many mine sites, thin soils or poor initial soil quality precludes stripping and replacement, necessitating the use of a manufactured soil substitute created from crushed spoil and various amendments. A common solution in Pennsylvania has been the addition of organic material and mineral fertilizer to either the stockpiled soils or crushed spoil to create a material capable of supporting seed germination and establishing initial plant cover.

One class of organic amendments being increasingly used for mine reclamation is biosolids, which are municipal and industrial wastewater treatment plant byproducts that possess a high organic-carbon content, contain valuable plant-available nutrients, and have a high water holding capacity. Municipal sewage sludge is probably the most common biosolid used for mine reclamation, but many industrial and food processing operations can yield similar materials. These materials are often disposed of as a solid waste, but biosolids are now widely recognized by regulators as a beneficial soil amendment and are increasingly being used in agricultural and mine reclamation activities. Biosolids offer the double advantages of superior vegetative establishment on disturbed soils for the mine operator, and reduction of landfill disposal costs for the biosolids generator.

The Soil Foodweb

In healthy soil, there are typically millions of microscopic organisms that live in the soil and around the roots of plants. The environment that these organisms inhabit and the ways in which they interact with each other and with plants is called the soil *foodweb*. There is an optimum balance of soil air, water, nutrients, and different microorganisms that allows plants to establish and thrive. Healthy soil should have a developed structure with voids for soil air and water, a balanced supply of plant-available macro- and micro-nutrients, as well as contain beneficial species of bacteria, fungi, nematodes, and protozoa, which are often missing in severely disturbed mine soils.

Developing the proper physical, chemical, and biological environments in the root zone can yield substantial benefits to mine soil reclamation projects. A balanced soil foodweb will: (1) suppress disease-causing and pest organisms; (2) retain nitrogen and other nutrients, such as calcium, iron, potassium, and phosphorus; (3) make nutrients available for plant growth at the times and rates that plants require; (4) decompose plant residues rapidly; and (5) produce good soil structure, improving water infiltration, oxygen diffusion, and water-holding capacity.

Disease suppression requires specific species of soil bacteria and fungi that compete with, inhibit, and parasitize disease-causing organisms. A plant uses a minimum of 25% of its fixed energy each year to feed beneficial organisms in the volume of soil around its roots. Pesticides and intensive earthmoving activities (bare soil for long periods) significantly reduce the diversity and amount of these beneficial organisms. In order to reestablish a viable soil foodweb, these organisms must be reintroduced through inoculation or through feeding with the right kinds of materials. A healthy soil contains a broad diversity of microbial types and most often contains species that consume, inhibit, or suppress the kinds of fungi that cause root rots and the kinds of nematodes that attack roots.

Nitrogen and other nutrients can leach out and be lost unless they are contained in less mobile forms in the soil until required for plant growth. Nutrient retention can occur when bacteria and fungi multiply in an organic-enriched environment and increase their populations in the soil. When bacteria and fungi multiply, they gather nitrates, ammonium, and other forms of nitrogen from the soil and convert it into protein in their bodies. Nitrogen in this form does not leach easily and is not lost as a gas. Products and cultural practices, such as biosolids applications that stimulate a "bloom" of bacteria or fungi reproductive growth, can be used as tools to achieve nutrient retention. When this function is working in the soil, lower rates of nitrogen and phosphorus can be applied with no reduction in crop yield. Organic amendments such as biosolids help retain the soils' N, P, S, Ca, K, Fe, etc, for plant use, and make these parameters less likely to leach into surface or groundwater resources.

Plant residues will only decompose if certain species of fungi and bacteria, the "decomposers," digest them and allow the nutrient recycling processes to occur. The ideal decomposition process forms large amounts of humus. The decay function breaks down plant residues and converts the food energy in fresh organic matter into biological forms that feed other soil organisms that perform different indispensable functions.

In order to maintain a well-aggregated soil structure (i.e., to improve or maintain good tilth), the organisms that glue, bind, and engineer soil structure and soil pores must be present. Good tilth or good soil structure allows optimum infiltration of air, water, and roots. Aggregates will not form unless sand, silt, and clay particles are "glued" together by the gums and gels that many species of soil bacteria produce. These aggregates are further strengthened against collapse by species of beneficial fungi that grow throughout the aggregate and physically bind it. The large pore spaces holding "reservoirs" of water must be built by larger organisms: microarthropods, earthworms, beetle larvae, enchytraeids, etc. The better the set of soil organisms producing resilient structure, the more "strength" a soil will have to resist damage, such as by vehicle passage.

Site Backgrounds

The four biosolids application sites, referenced herein as the PS, MS, SM, and PAC sites, were surface bituminous coal mines located in central Pennsylvania. The mines were situated on ridge crests above incised stream valleys, and discharged through erosion and sedimentation controls during the application periods. Reclamation typically progressed in phases, with biosolids application occurring following regrading of mine spoils and, when employed, replacement of stockpiled soils. Biosolids and fertilizer were applied one time on each regraded area, incorporated, and then seeded.

The applied biosolids were a "mine mix" consisting by dry weight of approximately 57% wood chips and 43% municipal sludge cake obtained from the Philadelphia Water Department (wastewater treatment solids). The mine mix was applied to achieve 60 dry tons of sludge per acre, equivalent to 332 wet tons as received when accounting for the moisture content of the mix material. Spreading occurred between April 15 and September 15 using conventional tractor-towed agricultural manure spreaders. After initial spreading, the mine mix was incorporated into the upper 6 to 12 inches of the regraded spoil surface using a chisel plow. Lime additions and any needed N-P-K fertilizers were applied on a site-specific basis as determined by nutrient analysis of the stockpiled soil or spoil.

Between 1993 and 1998, Gannett Fleming monitored soil and water quality on the four sites to satisfy land application permit reporting requirements administered by the Pennsylvania Department of Environmental Protection (PADEP). Following completion of the monitoring programs, Gannett Fleming examined these data sets to quantitatively evaluate the impact of the four application projects on water quality and the regulatory-selected soil quality parameters of nutrient levels and cation exchange capacity (CEC).

METHODS

Water quality monitoring points surrounding the application sites were selected in accordance with PADEP requirements to represent upstream and downstream conditions in receiving streams, downgradient groundwater discharges, and private water supplies. Sample parameters included a wide range of physical and chemical parameters, including nutrients and EPA priority pollutant heavy metals. The PADEP monitoring schedule for the application sites included collection of two background samples prior to biosolids application, and quarterly sample collection concurrent with and following biosolids application until the PADEP released the sites from further sampling. The water sampling duration ranged from 1 to 2 years following application.

Soil samples for PADEP reporting were collected from representative plots within the application areas of each mine site, with the number of samples varying depending on the size of the site. Samples were collected from the upper 6 to 8 inches of the soil surface by grab methods. Laboratory analyses of soil macro- and micro-nutrient levels and exchangeable cations were performed by the Agricultural Analytical Services Laboratory (AASL) of the Pennsylvania State University. The AASL provided results in the form of recommendations for liming and nutrient amendments for each sample based on the determined background soil levels, type of desired cover crop, and regional climatic conditions. In this study, initial pre-biosolids application samples were collected on three of the four sites, with no background sample required for the SM site. Additional samples were then collected on all four sites annually following biosolids application until the PADEP released the sites from further sampling. The duration of soil sampling ranged from 3 to 4 years following application.

RESULTS

The following presents the findings of the water and soil quality analyses for the four sites in composite, with discussion of the specific factors that may influence the results observed for each of the parameters considered.

Water Quality

After an analytical review of the water quality sampling programs for the four application sites, it was determined that the data sets were insufficient in size to reliably determine differences in water quality conditions due to biosolids application. All data in this study were collected solely for regulatory compliance purposes, which did not lend itself to a proper statistical design and analysis (treatment vs. effect). The PADEP required only two initial background samples and this proved inadequate to quantify baseline water quality conditions that existed prior to biosolids application. Valid analysis would require a minimum of one year of pre-application water quality baseline data, coupled with control samples from an area with no biosolids amendment or solely conventional mineral fertilizer amendment. No significant isolation of treatment vs. effect can be drawn, so the water quality analysis is not presented in this paper.

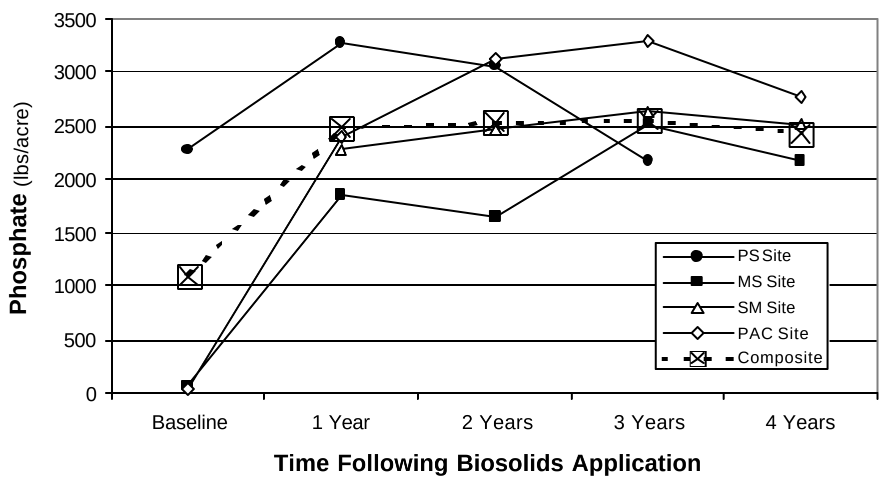
Soil Quality

The soils data sets were similarly shaped by the regulatory requirement of one round of background samples. However, these have been found more relevant because the post-application information covers a longer period than the water quality sampling, and the reported soil parameters are not expected to be as heavily influenced by seasonal fluctuations. Overall trends in soil parameters were found to be reasonably consistent over time and between separate sites. The results discussed here are for the soil macro- and micro-nutrient levels of phosphate, potash, and magnesium nutrient levels and overall soil CEC. These parameter trends are presented in Figures 1 – 4, respectively, as the composite trends for all the samples of each individual site and as a composite of the sampling data for all four sites.

Phosphate

Phosphate is not a highly mobile parameter (as compared to nitrate) and is normally only lost through erosion and plant uptake. In Figure 1, phosphate levels on the individual biosolids application sites varied between 1,650 and 3,280 pounds per acre (lbs/acre) in the years following application. The composite trend for all site data indicates little variation with time from an average of about 2,500 lbs/acre. None of the composite averages for years following application are significantly different from preceding post-application years. These data indicate that a good cover crop has been established and that erosion has not removed this plant-essential macro-nutrient provided by the biosolids application. Due to the large initial phosphate application rate, it is likely that any reduction in soil levels due to plant uptake has been overshadowed during these first four years.

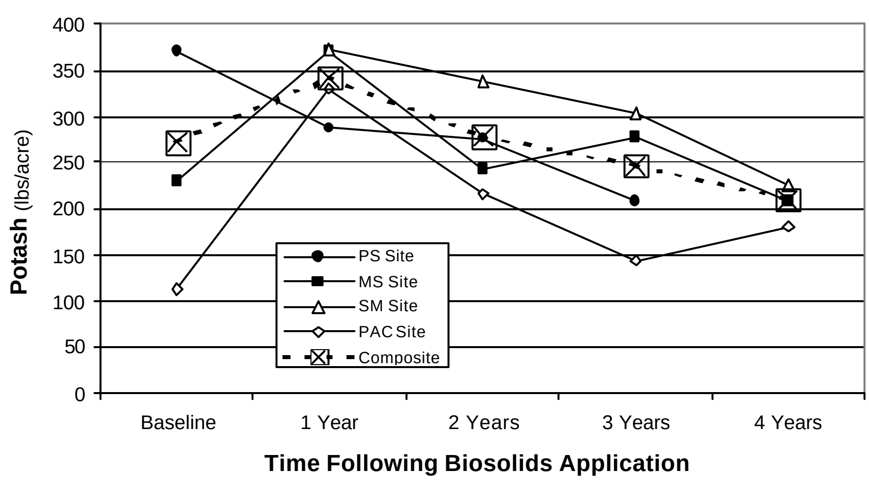
Figure 1. Phosphate Nutrient Levels with Time



Potash

Potash levels shown by Figure 2 range from a high of 373 lbs/acre to a low of 144 lbs/acre in a relatively consistent diminishing trend for the individual sites. This is apparent in the composite trend as well, with potash levels decreasing by approximately 15 percent each year following biosolids application. These decreases are highly significant between Year 1 and Year 2, and significant between Year 2 and Year 3, but not significant between Year 3 and Year 4. These decreases in potash levels are in agreement with the typical plant uptake rate of 200 lbs/acre for the cover crop of cool season grasses. The leveling off of potash removal between Years 3 and 4 may indicate the beginning of nutrient cycling in the newly established biosolids-amended mine soil.

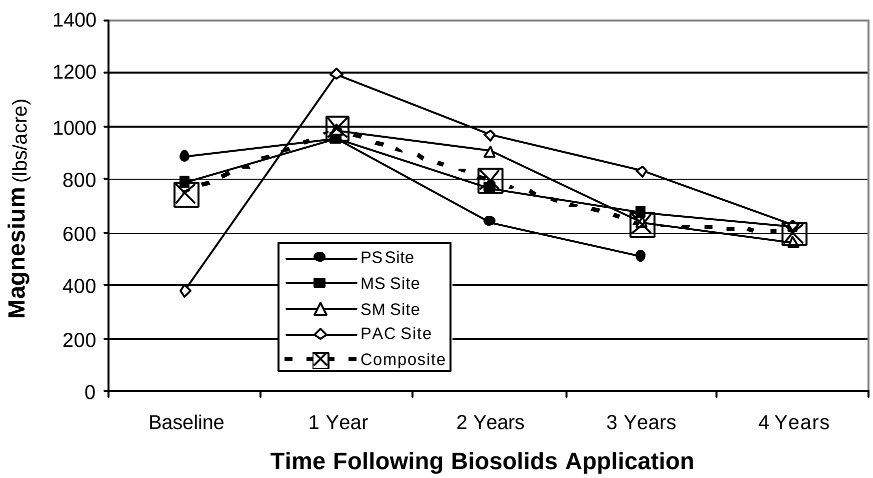
Figure 2. Potash Nutrient Levels with Time



Magnesium

Trends for magnesium levels, shown by Figure 3, are similar to those for potash and range from a high of 1,195 lbs/acre to a low of 507 lbs/acre. The average decrease of the composite trend is also about 15 percent per year following biosolids application and appears to begin an asymptotic reduction in change in Year 4. Decreases in magnesium levels are highly significant between Year 1 and Year 2, and between Year 2 and Year 3, but are not significant between Year 3 and Year 4. Soil magnesium is a moderately leachable nutrient and greater amounts are often found in the subsoil than in upper parts of the profile. The initial decreases in soil magnesium are likely due to plant removal and may indicate that the more mobile forms of magnesium (primary, acid soluble, and exchangeable) have moved below sampling depth, leaving mainly the organically-complexed material in the top horizon.

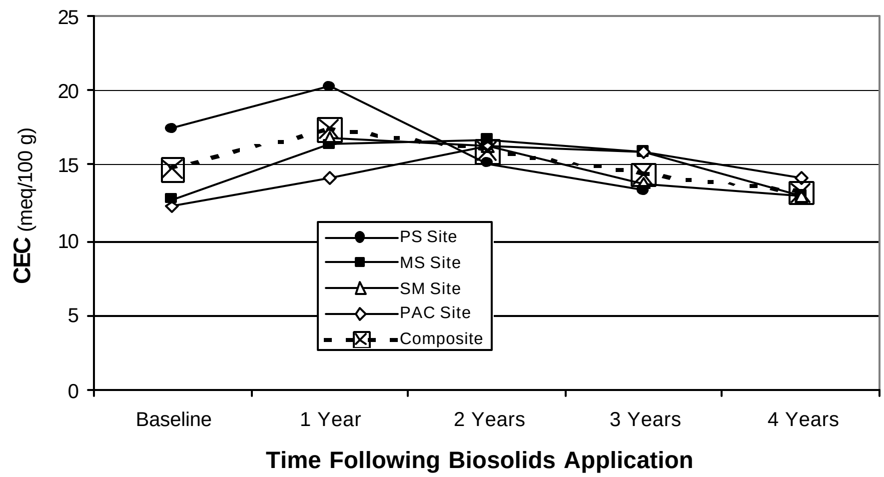
Figure 3. Magnesium Nutrient Levels with Time



Cation Exchange Capacity

CEC trends between the four sites are relatively well grouped on Figure 4, ranging from a high of 20.2 meq/100g to a low of 12.9 meq/100g for the individual sites. The composite trend is consistent over time and averages a decrease of approximately 9 percent per year following biosolids application. The decrease between Year 2 and Year 3 is highly significant, while the decreases between Year 1 and Year 2, and between Year 3 and Year 4, are just under the threshold of significance. CEC can vary depending on soil pH, and broad trends in the soil data suggest that in the initially acidic soil samples, pH rose as expected after the lime and biosolids application. The soil pH and CEC decreased over time in these same samples, and this is attributed to acid deposition (rain) and the formation of organic acids. In the initially acidic and low CEC level pre-application soils, biosolids and lime raised the CEC significantly.

Figure 4. Cation Exchange Capacity with Time



DISCUSSION

Regulations governing the land application of biosolids stress that these materials should pose no greater risk to the environment and the public health than conventional reclamation materials (mineral fertilizers and lime). With this as the guiding principal, the required regulatory sampling is heavily slanted towards the more easily understood and commonly measured soil chemistry parameters. This study found that this type of testing stresses only the "chemical" fertilizer benefits of biosolids, and provides a poor evaluation for this proven reclamation method. Of the three primary soil quality factors - physical, chemical, and biological - the least measurable benefits from biosolids applications are related to soil chemistry. The greatest benefit of biosolids is in helping rebuild soil structure and restock the soil foodweb for beneficial biological organisms.

Biosolids-amended soils by definition have a higher organic matter content and, therefore, increased water holding capacity, tilth (porosity), nutrient holding capacity, buffering capacity, availability of soil minerals, activity of soil microorganisms, and both short- and long-term improvement in soil fertility. The authors have worked with biosolids in numerous reclamation and agricultural settings and found their use to be highly beneficial in establishing and maintaining plant growth in harsh conditions. In our studies provided to regulators, yields of plant biomass and health evaluations of plants cultivated in biosolids-amended soil were always significantly higher than the control samples (untreated soil). Laboratory surface and groundwater water quality assessments showed that biosolids were a clean, low-impacting source of plant nutrients, and have lower non-point source pollution potential than commercial fertilizers. Nitrogen and phosphorous content of the surface runoff and groundwater recharge from biosolids-amended soils were less than that of fertilizer-amended soils, even in the extreme case where the total nitrogen application rate was 10 times greater for the biosolids than for the mineral fertilizer.

CONCLUSIONS

The trends in soil nutrient content and CEC observed on the four biosolids application sites are consistent with establishment of viable soil foodwebs within the reclamation soils. Biosolids are an effective means of improving soil structure and nutrient content on mine reclamation sites. However, current regulatory monitoring programs may not provide sufficient background information to reliably assess the benefits and impacts of biosolids applications, particularly with regard to water quality and the physical and biological properties of reclamation soils.

REFERENCES

Fixen, P. E. and J. H. Grove. 1990. Testing Soils for Phosphorous. In: R. L. Westerman (ed) Soil Testing and Plant Analysis, Book 3. Soil Science Society of America , Madison, WS.

Harby V. A., Russelle, M. P., and E. O. Skogley. 1990. Testing Soils for Potassium, Calcium, and Magnesium. In: R.L. Westerman (ed) Soil Testing and Plant Analysis, Book 3. Soil Science Society of America , Madison, WS.

Herlihy, T. E., and W. H. Billings. 1996. An Environmental Assessment and Feasibility Study of Using Vegetable Tannery Biosolids as a Soil Conditioner/Plant Growth Supplement. Journal of the American Leather Chemists Association. 1996 (91), No. 3, pg.64-79.

Herlihy, T. E. (1999). An environmental assessment of vegetable tannery biosolids as an organic fertilizer and soil conditioner. In: G. G. Gross, R. W. Hemingway, T. Yoshida, Plant Polyphenols 2: Chemistry, Biology, Pharmacology, Ecology. Kluwer Academic/Plenum Publishers, New York, N.Y. (in press).

Kuhlman, L. R. 1992. Value of composting cattle feedlot manure. Australian Lot Feeders Association Conference (BEEFEX 92) Coffs Harbour, New South Wales, Australia.

Pennsylvania State University Agronomy Guide, 1997-1998. 1994. University Park, PA.

Stevenson, F.J. 1991. Organic Matter-Micronutrient Reactions in Soil. In: J. J. Mortvedt et al (ed), Micronutrients in Agriculture, Book 4. Soil Science Society of America, Madison, WS.

Stomberg, A. L., Hemphill, J. R., and V. V. Volk. 1894. Yield and Elemental Concentration of Sweet Corn Grown on Tannery Waste Amended Soil. Journal of Environmental Quality (13), No.1, pg. 162-166.