Factors Affecting Decomposition Properties of Paper Mill Sludge Spread on Mine Tailings

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Abstract
Paper mill sludge is being used increasingly as means of remediating mine-contaminated soils but in order to ensure the refinement and success of these remedial prescriptions, an understanding of sludge decomposition properties is necessary. This study examines the effect of sludge age and depth on decomposition dynamics for paper mill sludge applied to a copper-uranium mine tailings site in Rio Algom's Pronto Waste Management Area near Elliot Lake, Ontario. Decomposition was assessed in the field by weight loss of sludge in litterbags throughout the course of a year. The two-year-old sludge yielded the highest decomposition rates in the field experiments**.** Furthermore, decomposition rates were highest in the fresh surface sludge, decreasing with depth but this trend was reversed in older sludge, whereby rates were lowest near the surface, increasing with depth.

INTRODUCTION
Bradshaw (1983) indicated that the first step in rebuilding a damaged ecosystem is to provide a soil substrate conducive to primary vegetation establishment, often through the incorporation of organic matter. Recently, there has been an increasing interest in the use of industrial biosolids applications to degraded lands as a means of augmenting organic matter in degenerated soils. The use of biosolids in land reclamation efforts also provides a potential solution to the growing concern of proper industrial waste disposal. Previous studies examining paper mill waste have shown that adding a layer of sludge over the surface of the tailings is more effective than incorporating it into the soil (Cabral *et al*., 1998; Tisch *et al*., 2000). This organic cover impedes oxygenation of the tailings, reducing acidification and provides a more suitable substrate for vegetation establishment. However the relative success of paper mill sludge is largely dependent on the application rates (Biondini *et al*., 1985; Redente and Hargis, 1985). As such, an understanding of the decomposition properties of the paper mill sludge is necessary in order to formulate proper sludge application prescriptions for site amendment.

The purpose of this study was: 1) to determine the effects of age on the decomposition rates of various ages of paper sludge applied to copper-uranium tailings, 2) to determine the effects of sludge depth on decomposition rates, 3) to compare the effectiveness of Sentury® rock bags with standard 1-mm mesh litterbags, and 4) to verify that these rates justify the use of paper mill sludge as a potential source of organic input in long-term management practices of mine-damaged soils.

Study Site
Field plots were located west of Spragge, near Elliot Lake, Ontario (46°23'N, 82°38'W), in Rio Algom's Pronto Waste Management Area. The mine ceased production more than 30 years ago, and since that time attempts have been made to reclaim the land. In the 1970's revegetation efforts were highly successful, except in the areas covered by fine tailings. Since 1998 these areas were subjected to paper sludge applications for several successive years. Each year, the sludge was applied to a new plot at a depth of approximately 0.5-1.0m over a total area of 23ha, permitting a study of the decomposition rates over several years after a single application to the plot. All of the plots were

limed prior to sludge application with 10 tons ha^{-1} of ground dolomitic limestone. The most recent application of paper mill sludge to the site took place in February 2002.

METHODS

The paper mill sludge used in this experiment was generated by St Marys Paper Limited, located near Sault Saint Marie, Ontario. Samples were obtained from areas within the Pronto Waste Management Area where sludge had been applied over different sections of tailings over several years. At the time of this study, the 2002 site represents the <1-year-old sludge, the 2001 site, the 2-year-old sludge, the 2000 site, the 3-year-old sludge, and the 1999 site, the 4-year-old sludge.

12cm by 12cm litterbags were created using 1-mm nylon mesh (Post and Beeby, 1996; Bryant *et al*., 1998). As well, bags of approximately 15cm by 15cm were fabricated by cutting Sentury® rock bags in half. Surface bags were filled with composite sludge samples (40g in the mesh bags, 70g in the rock bags), which were collected by randomly obtaining sub-samples of sludge from the surface of a variety of areas within each site and combining them. Once sealed, the bags were weighed and placed in the sites from which the sludge had originated (2002, 2001, 2000, and 1999).

To study the effects of depth on decomposition rates, pits were dug the depth of the sludge application. 70g of sludge from the bottom of the pit were taken by digging out small holes around the bottom of the pit and added to the rock bags. These bags were weighed, sealed, and placed in the holes. They were then covered with the removed sludge. At the centre of the pit sludge samples were obtained in a similar manner, added to the bags and the bags were placed in the holes surrounding the centre of the profile. The remainder of the sludge was replaced into the pit. This procedure was repeated for the 9 sample areas located in each site.

All bags were placed around wooden posts arranged in rows, ensuring that surface bags were placed in contact with the sludge, under any existing vegetation. The bags surrounding the first row of posts were recovered after one month in the field, the second set after 2 months, the third set after 7 months (2001) and 3 months (2002). Once collected, the dry weights were determined. Also, the mean moisture retention in the sludge was calculated for each site and depth and these values were used for moisture corrections on the initial weights of the sludge. Using these corrected weights, the amount of dry weight loss over the exposure period was calculated and standardized to % dry weight loss day^{-1}.

All data was analyzed with Spearman's Rho and Kruskall-Wallis using SPSS 11.0 software.

RESULTS

2001 Field Studies

Results indicated that decomposition rates were highest in the 2-year sludge, gradually decreasing with age. The decomposition rates for litterbags collected after 1 month in October, 2001 were double those left in the field over a period of 2 months that were collected in November, 2001, and about 7 times higher than litterbags that were left for 8 months over fall and winter, collected in May 2002 (Figure 1). The total mean decomposition rate for all litterbags in 2001 was approximately 0.75% dry weight loss day^{-1}.

2002 Field Studies

Similarly, 2002 field studies show that decomposition rates were highest in the 2-year-old sludge, decreasing with age. The mean decomposition rate for litterbags collected after 1 month in June, 2002 were double those left in the field over a period of 2 months, collected in July, 2002, and about 3 times higher than litterbags left in the field for 3 months, collected in August, 2002 (Figure 2). The total mean decomposition rate for all litterbags in 2002 was approximately 0.47% dry weight loss day^{-1}.

In order to study the effects of depth, an alternate method to the standard 1-mm mesh litterbags was necessary. The two types were found to be significantly different with Sentury® rock bags yielding higher surface decomposition rates than the mesh bags (Figure 3).

When studying the effects of depth on decomposition rates, surface sludge decomposed most rapidly, with rates decreasing with depth during the first exposure period. This trend was consistent in the newest sludge throughout the course of this study. Furthermore, there was a shift in this pattern seen in the second exposure period in the 2-year-old sludge and the third exposure period for the 3-year-old sludge, whereby the greatest rates of decomposition were evident t the bottom of the profile, decreasing with proximity to the surface.

DISCUSSION

Results obtained from the 2001 field studies revealed a mean decomposition rate of 0.75% dry weight loss day^{-1}, leading one to conclude that the sludge would completely disappear after only several months. This seems a surprisingly high rate since sludge still occurs on a 4-year-old site. Post and Beeby (1996) demonstrated similar decomposition rates (0.85% dry weight loss day^{-1}) for litterbag studies after examining the rate of cellulose-strip decomposition in metal-contaminated roadside soils during the fall months. More importantly, their results show that cellulose decomposition rates obtained for October, 1990 were substantially higher than in the fall of 1985, suggesting that decomposition rates were strongly affected by variation in climate. As such, it follows that changes in microclimate will impact the rate of sludge decomposition. This theory prompted a second field trial in the summer of 2002 to determine the effects of sludge depth on decomposition rates.

Due to the porous nature of the standard 1-mm nylon mesh litterbags, an alternate method was required to minimize the amount of sludge flowthrough. Sentury® rock bags were chosen because of their small pore size which minimized sludge entry or escape from the bags while allowing air and water to circulate freely. As a comparison, these bags were placed on the surface of the sludge, along with the mesh bags. Statistical analysis revealed that there was a significant difference between the mesh and the rock bags with respect to the mean surface sludge decomposition rates. Although the reasons for this difference are not fully understood, the Sentury® rock bags still proved a useful tool for subsoil decomposition studies.

Interestingly, there was an effect of depth on the decomposition rates such that rates decreased with depth upon initial application. However, it was apparent that as sludge aged decomposition rates were lowest near the surface and increased with depth, as seen with the 2- and 3-year-old sludge. In related research, Bryant *et al*. (1998) stated that climate and intrinsic chemistry govern leaf litter decomposition dynamics and that the initial C:N (carbon to nitrogen) ratio of the organic matter were good predictors of the litter decomposition. Further research revealed that that soil moisture (Bryant *et al*., 1998) and temperature (Williams and Gray,

1971) were the primary controlling factors in surface litter decomposition dynamics. Barbour *et al*. (1999) noted that it is impossible to separate the effects of temperature and moisture because they are not environmentally independent and extreme levels of either will exceed the tolerance of decomposers. Indeed, there was a significant correlation between decomposition rates with both temperature and moisture throughout the course of this study.

Moreover, paper sludge has a moderate to high C:N in fresh sludge (Evanylo *et al*., 1996; Nemati *et al*., 2000). If decomposition was rapid in the surface sludge during the first year after application, it is possible that much of the available nitrogen would have been immobilized by soil bacteria, leaving higher C:N ratios in the depths below. Consequently, the remaining recalcitrant carbon on the surface would not decompose as rapidly on the surface, even if climatic conditions remained favourable. In order to test this hypothesis, further research concerning the C:N dynamics throughout the sludge is necessary.

CONCLUSION

Although differences were recorded between the two bag types, rock bags still provided some insight to the decomposition dynamics of paper sludge. It seems as nitrogen becomes immobilized in the surface layer, sludge decomposition occurs more rapidly in the depths below for several years following application. Further research is required to test this hypothesis by examining the effects of C:N ratios with depth for various ages of sludge. Finally, a long-term study of the paper sludge should be established in order to fully understand the temporal implications of sludge depth and to further our understanding of the use of this biosolid in landscape amendments.

REFERENCES

Barbour, M.G., Burk, J.H., Pitts, W.D., Gilliam, F.S., and Schwartz, M.W. 1999. Terrestrial Plant Ecology: Third Edition. Benjamin/Cummings, an imprint of Addison Wesley Longman, Incorporated, New York.

Biondini, M.E., Bonham, C.D., and Redente, F. 1985. Relationships between induced successional patterns and soil biological activity of reclaimed areas. Reclamation and Revegetation Research 3:323-342.

Bradshaw, A.D. 1983. The reconstruction of ecosystems. Journal of Applied Ecology 20:1-7.

Bryant, D.M., Holland, E.A., Seastedt, T.R., and Walker, M.D. 1998. Analysis of litter decomposition in an alpine tundra. Canadian Journal of Botany 76:1295-1304.

Cabral, F., Vasconcelos, M.J., and Cordovil, C.M.d.S. 1998. The value, use, and environmental impacts of pulp-mill sludge additions to forest and agricultural lands in Europe. Environmental Reviews 6:55-64.

Evanylo, G.K., Daniels, L.W., and Li, R.S. 1996. Papermill sludge composting and compost utilization. Proceedings of the Composting in the Carolinas Conference, Myrtle Beach, South Carolina.

Katterer, T., Reichstein, M., and Andren, O. 1997. Temperature dependence of organic matter decomposition: a critical review using literature data analyzed with different models. Biology and Fertility of Soils 27:258-262.

Nemati, M.R., Caron, J., and Gallichand, J. 2000. Using paper de-inking sludge to maintain soil structural form: field measurements. Soil Science Society of America Journal 64:275-285.

Post, R.D. and Beeby, A.N. 1996. Activity of the microbial decomposer community in metal-contaminated roadside soils. Journal of Applied Ecology 33:703-709.

Redente, E.F. and Hargis, N.E. 1985. An evaluation of soil thickness and manipulation of soil and spoil for reclaiming mined land in Northwest Colorado. Reclamation and Revegetation Research 4:17-29.

Tisch, B., Beckett, P., Okonski, A., Gordon, C., and Spiers, G. 2000. Remediation and revegetation of barren copper tailings using paper mill sludge: an overview. Presented at the CLRA Annual Meeting, Edmonton, Alberta, Canada.

Williams, S.T. and Gray, T.R.G. 1971. Decomposition of litter on the soil surface. Soil Micro-organisms. Oliver and Boyd, Edinburgh 1971

Zibilske, L.M., Clapham, W.M., and Rourke, R.V. 2000. Multiple applications of paper mill sludge in an agricultural system: soil effects. Journal of Environmental Quality 29:1975-1981.

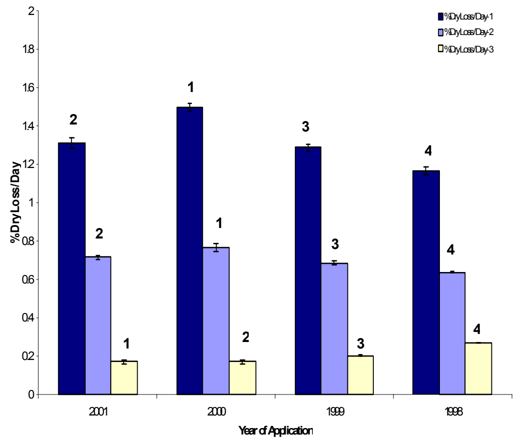

Figure 1. Mean decomposition rates in litterbags in the field over 1,2, and 8 months (2001) for various ages of paper sludge (mean +/- SE)

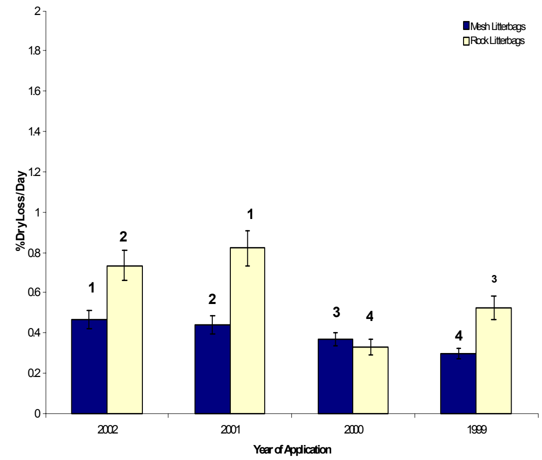

Figure 3 Mean Decomposition rate in 1-mm mesh litterbags and Sentury rock litterbags in the field for various ages of paper sludge (mean +/1 SE)

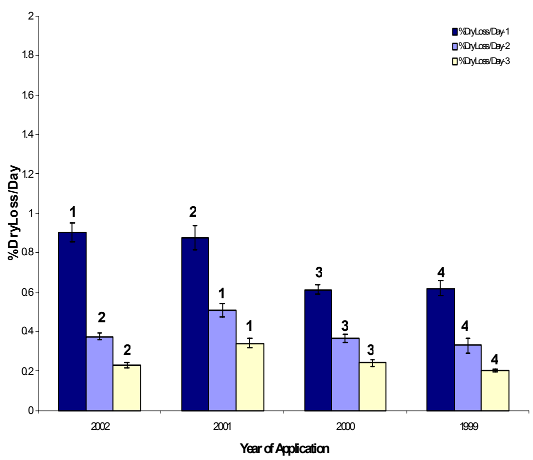

Figure 2 Mean decomposition rate in litterbags over 1,2, and 3 months (2002) for various ages of paper sludge (mean +/- SE)

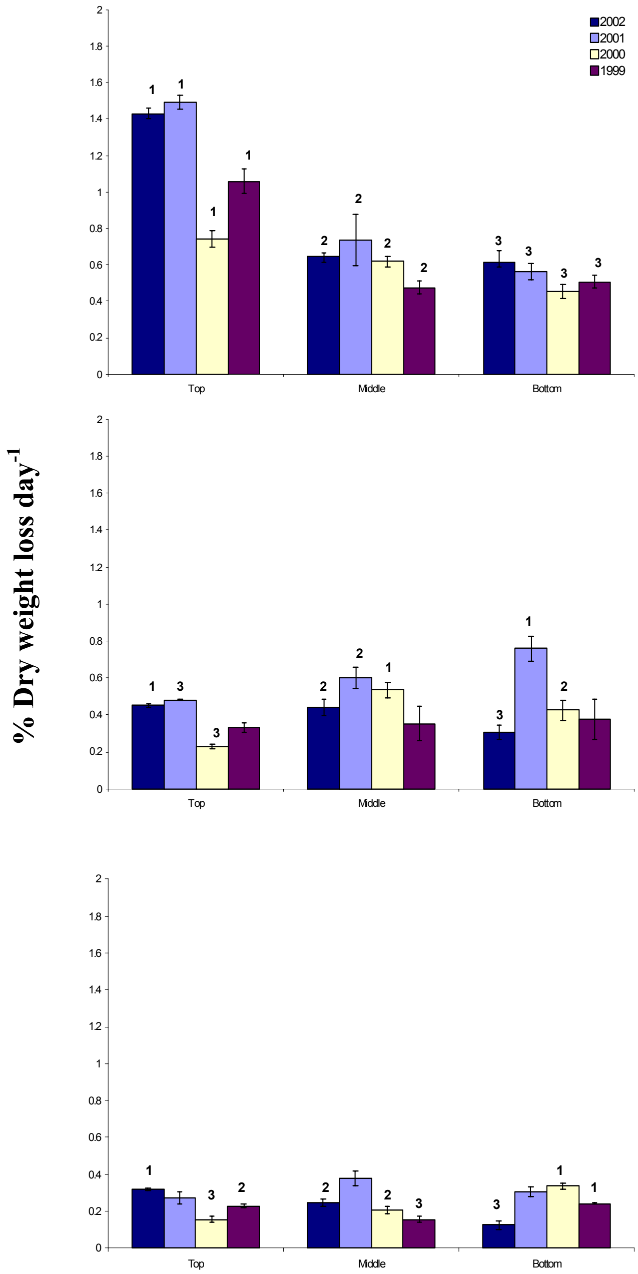

Figure 4. Mean decomposition rates in rock bags in the field over 11,2, and 3 months at various depths for sludge applied in different years.