MUSHROOM COMPOST AND PAPERMILL SLUDGE INFLUENCE DEVELOPMENT OF VEGETATION AND ENDOMYCORRHIZAE ON ACID COAL-MINE SPOILS

Willis G. Vogel and Frederick M. Rothwell[1/]

Abstract.--Several rates of spent mushroom compost and papermill sludge were evaluated as amendments in revegetating abandoned acid mine spoils (pH 3.3 to 4.1). In a greenhouse study, the combined yields of five harvests of a perennial ryegrass (Lolium perenne)-red clover (Trifolium pratense) mix were 2 to 4 times higher in spoils amended with a 1:1 sludge-compost mix and with compost alone than in spoils amended with sludge alone or with lime plus mineral fertilizer. Yields increased with each higher rate of compost, sludge, or mix, i.e., 25, 50, and 75 g of air-dry material per 1000 g of air-dry spoil. Herbage yields in the lime-fertilizer pots declined rapidly after the second harvest, but continued fairly steady through the five harvests in the compost and sludge treatments. Results followed a similar pattern in field plots except that herbage yields were more nearly alike in sludge and compost treatments. Compared to the lime-fertilizer treatment, endomycorrhizal formation was enhanced by additions of papermill sludge and a 1:1 mixture of sludge and compost, but inhibited at all levels of treatment with mushroom compost alone. High levels of phosphorus in the compost were most likely responsible for this inhibition of endomycorrhizae. These experiments show that mushroom compost and papermill sludge are useful materials to aid revegetation of acid spoils, though the long-term effect of mycorrhizal inhibition in compost-treated spoils could not be predicted in this study. The estimated cost of applying these organic materials was about 2.5 times that of applying appropriate rates of lime, mineral fertilizer, and mulch, but yields of vegetation also were 2 to 3 times greater from the compost and sludge amendments.

INTRODUCTION

Acid spoils abandoned after surface mining for coal are commonplace in some areas of the Eastern United States. Most of these sites were mined before State and Federal laws and regulations were enacted to control mining and reclamation practices. Some of these abandoned mines have been revegetated by natural processes, though in some localities barren or sparsely vegetated spoils still exist and need treatment to support vegetation.

Acid-mine spoils usually lack nitrogen and organic matter, often have low levels of plant available phosphorus, and have little or no structural stability. One procedure in reclaiming these spoils

[1/]W. G. Vogel, Range Scientist (retired), and F. M. Rothwell, Microbiologist (retired), are with the USDA Forest Service, Northeastern Forest Experiment Station, Berea, KY.

Proceedings America Society of Mining and Reclamation, 1988 pp 206-213

DOI: 10.21000/JASMR88020206

https://doi.org/10.21000/JASMR88020206

is to apply agricultural lime and mineral fertilizers to neutralize acidity and enhance plant growth. Sometimes, topsoil or better quality spoil is available to cover the acid spoil. Abandoned mine sites in some localities have been successfully revegetated by using large inputs of municipal wastes such as sewage sludge (Mason 1985, Sopper and Kerr 1979). In southeastern Ohio, a sludge-like residue recovered by primary and secondary treatments of effluent from the Mead Paper Corporation plant (Kraft process) at Chillicothe has been used in successfully reclaiming acid-mine spoils (Hoitink and Watson 1980, Hoitink et al. 1982). Spent mushroom compost is another industrial residue that is available in some localities for mined-land reclamation use.

Interest in reclaiming surface-mined lands often focuses on success in amending acidic spoils and promoting vegetational growth. Though not so conspicuous, the biological components of soil also play a vital role in the development and maintenance of vegetation (Vogel 1981). Studies by Wilson (1965) on rhizosphere microorganisms, and later by Schramm (1966) on microbial symbionts, were among the first to define and demonstrate the significance of microorganisms in minesoil revegetation. More recently, microbial interactions with plants have been shown to be some of the most influential factors in aiding plant establishment, particularly those interactions between mycorrhizal fungi and their host plants (Allen 1985, Cundell 1977, Fresquez and Lindemann 1982). The significance of the formation of endomycorrhizae by VAM fungi is most apparent where levels of mineral nutrients in the soil limit plant growth. In such cases, an extensive mycelium or thread-like growth produced by the fungi permeates the rhizosphere and increases manyfold the capacity of the host plant to absorb nutrients. Where levels of mineral nutrients, particularly P, are high in soils, little or no plant-fungal association is observed.

Papermill sludge has been frequently used for amending acid-mine spoils; however, less is known about spent mushroom compost as an amendment for these sites. Therefore, in the spring of 1983, studies were set up to compare this compost with papermill sludge and with lime plus fertilizer as treatments for acid-mine spoils. Herbage yields were used as the primary means for evaluating the comparative effectiveness of the amendments; the influence of these amendments on formation of endomycorrhizae by the VAM fungi also was evaluated.

MATERIALS AND METHODS

Greenhouse and field studies were established using acidic spoils from abandoned surface mines in southeastern Ohio. Spoil for the greenhouse study was collected from two sites on the Wayne National Forest: Hanging Rock in the Ironton Ranger District and the Weltzheimer Tract near Nelsonville in the Athens Ranger District. Plots for the field study were established at the Hanging Rock site only.

Greenhouse Pot Study

Pots were filled with 2,000 g of spoil screened through a 13-mm mesh sieve. For each spoil, 44 pots were prepared to accommodate 4 replications of 11 treatments as follows:

- None (Control)
- Lime plus fertilizer
- Papermill sludge at three rates
- Mushroom compost at three rates
- A 1:1 mix of papermill sludge and mushroom compost at three rates

For the lime plus fertilizer treatment, 7 g of laboratory grade $CaCO_3$ (precipitated chalk) was added per 1,000 g of Hanging Rock spoil and 5.5 g per 1000 g of Weltzheimer spoil. The buffer pH test of Shoemaker et al. (1961) was used to determine liming rates. Fertilizer added was 50 ppm of N as NH_4NO_3; 100 ppm P_2O_5 as basic calcium phosphate; and 25 ppm K_2O as KCl.

The three rates of papermill sludge and compost were 25, 50, and 75 g of air-dry material per 1,000 g of air-dry spoil. This is similar to a field application of 56, 112, and 168 t/ha (15-cm furrow slice). For the three rates of mix, one-half of these rates of each material was used.

The amendments were mixed thoroughly in the spoils. The pots were then seeded by placing 50 seeds of perennial ryegrass (*Lolium perenne*) on one-half of the surface area of a pot and 50 seeds of red clover (*Trifolium pratense*) on the other half. Water was added equal to 20 to 25 percent of the weight of the spoil-amendment mix. Thereafter, pots were watered daily to maintain this moisture level.

The first harvest of vegetation was made 60 days after seeding. Four succeeding harvests were made periodically through the next 10 months. The plants, harvested separately by species, were cut 5-7 mm above the soil surface. Vegetation was ovendried and weighed.

Field Study

For the field study, three replications of seven treatments were applied on 16- by 16-m plots at the Hanging Rock site near Ironton, OH. The treatments were agricultural lime (16 t/ha) plus fertilizer (560 kg/ha 10-10-10); papermill sludge and mushroom compost each at two rates equivalent to 76 and 112 air-dry t/ha; and a mix of sludge and compost at two rates equivalent to 38 and 56 air-dry t/ha of each material. The high rate of sludge and compost treatments was similar to the intermediate rate used in the greenhouse study. The sludge and compost were applied wet; the materials used contained about two-thirds water by weight. Lime, papermill sludge, and compost were disked about 13 cm into the spoil. Fertilizer was broadcast on the tilled surface of the lime plus fertilizer plots, and a mix of grass and legume seed was sown over the entire area. Herbage yields were determined in September by clipping vegetation from five randomly placed 0.223-m^2 quadrats in each plot. The herbage was oven-dried and weighed.

Endomycorrhizae Analysis

Roots from plants in greenhouse pots and field samples were soaked in water to remove the bulk of the soil material, then carefully washed free of adhering soil with a fine spray of water. Terminal portions of the root system including the finest order of root branching were cut into segments approximately 2.5 cm in length and stained to detect presence of VAM fungi (Phillips and Hayman 1970). Percent mycorrhizae was determined on the basis of microscopic observations of 100 stained root segments from each of the treated spoils. Spores were obtained by wet sieving the soil.

RESULTS AND DISCUSSION

Characteristics of Spoil Materials

Pertinent characteristics of the spoils used in the greenhouse study are listed in table 1. Bray P_1 phosphorus and pH of spoil samples collected from the greenhouse pots 10 months and five harvests after seeding are shown in table 2. The overall higher pH, and higher levels of phosphorus, calcium, and magnesium in the Hanging Rock spoil presumably resulted from an application of lime and fertilizer on that area the preceding fall. The pH of the spoils was adequately raised by all treatments except by the low rate of compost in the Weltzheimer spoil. Values of Bray phosphorus were higher in the compost treated spoils than in those treated with papermill sludge or the mix.

Characteristics of Organic Amendments

Some of the properties of the papermill sludge and mushroom compost are listed in table 3. The papermill sludge is especially high in calcium, and the compost high in P and K. The sludge contains a high percentage of kaolinite clay used in the papermaking process. Compost for growing mushrooms is prepared by mixing horse manure and straw with peat moss, brewers grain, gypsum, and lime. The compost used was stockpiled outdoors for about 6 months after removal from the mushroom plant. Nitrogen content was about 1 percent for the sludge and about 2.6 percent for compost. At the application rate of 112 air-dry t/ha the nitrogen content of the sludge was equivalent to 1,120 kg/ha and 2,800 kg/ha for the compost. The availability of the N in these materials relative to the mineral fertilizer was not evaluated. The sludge provided about 201 kg P/ha and 280 kg K/ha and the compost provided about 784 kg P/ha and 2,128 kg K/ha, at this application rate. The pH of the papermill sludge was 7.6 and the median pH of the compost samples was 6.8 with a 6.3 to 7.5 range.

Greenhouse Pots - Herbage Yields

Yields of herbage harvested 60 days after seeding were progressively higher with each added increment of the papermill

Table 1.--Characteristics of spoils collected from two locations in the Wayne-Hoosier National Forest in southeastern OH.

Spoil Characteristics	Sites: Hanging Rock	Sites: Weltzheimer
Textural class	Sandy clay loam	Sandy loam
pH	4.1	3.3
Bray P_1 (ppm)	4.6 (low)	0.6 (very low)
K (ppm)[a]	27 (very low)	24 (very low)
Ca (ppm)[a]	2,907 (high)	84 (very low)
Mg (ppm)[a]	1,242 (very high)	52 (low)

[a] Concentrations of K, Ca, and Mg were measured in double acid extract. Comparative qualitative values per Environmental Protection Technology Series EPA-670/2-74-070, October 1974.

Table 2.--pH and Bray P_1 phosphorus 10 months and 5 harvests after seeding in greenhouse spoils amended with lime and fertilizer, papermill sludge, or mushroom compost.

Treatments and Rates	Hanging Rock Spoil		Weltzheimer Spoil	
	pH	Bray P_1 (ppm)	pH	Bray P_1 (ppm)
Control	5.5	22.1	3.5	4.7
Lime & fertilizer	7.2	28.7	6.4	12.2
Sludge 25[a]	7.2	16.4	6.9	5.2
Sludge 50	7.2	10.9	7.0	6.4
Sludge 75	7.3	10.0	7.1	14.1
Compost 25	5.9	39.9	4.6	12.1
Compost 50	6.5	228.2	5.7	40.3
Compost 75	6.7	476.0	6.3	218.3
Mix 25	7.0	29.9	6.5	5.5
Mix 50	7.1	44.9	6.9	15.1
Mix 75	7.1	40.4	7.0	21.3

[a]Rates are grams of sludge or compost added per 1,000 grams spoil (air-dry basis). Mix was half sludge and half compost.

Table 3.--Some properties of papermill sludge and mushroom compost used to amend acid spoils[a].

Property	Papermill Sludge	Mushroom Compost
pH	7.6	6.8 (6.3 - 7.5)
N (%)	1.06	2.64
P (ppm)	1,825	7,148
K (ppm)	2,575	19,352
Ca (ppm)	197,897	66,857
Mg (ppm)	5,798	14,823
Fe (ppm)	4,425	6,183
Al (ppm)	23,026	5,273

[a]Analyses on ovendry material.

sludge, mushroom compost, and mix of the two materials. The highest yields resulted from the high rate of the mixed organic amendments. Yields from the low rate of compost were similar to the yields from the lime plus fertilizer treatment; pots with the low rate of sludge and mix yielded less than those with lime plus fertilizer.

Cumulative yields of herbage from five harvests are shown in table 4. These yields show the same general relationship among treatments as in the first harvest. Yield of clover increased more than yield of ryegrass after the first harvest, particularly with the compost and mix treatments. Yields from the low rate of sludge were similar to the yields in the lime plus fertilizer pots. All other treatments and rates exceeded the lime plus fertilizer treatment, some by as much as 500 percent. This seemingly is a result primarily of the higher levels of N, P, and K in the organic materials, especially the compost, though other benefits of the organic materials may also contribute to better plant growth. These benefits may include lower soil temperatures, increased infiltration and retention of water, increased availability of nutrients, and better soil aeration.

Field Plots - Herbage Yields and Cover

Results in the field plots supported the results in the greenhouse pots, in that the sludge and compost amendments produced much higher yields than did lime and fertilizer (table 5). In 1983, the high rate of compost produced the highest yield of herbage followed closely by the low rate of compost and high rate of mixed materials. In 1984, the highest yield was harvested from the plots with the high rate of papermill sludge followed by the high rate of mix and high rate of compost. Average vegetative cover was visually estimated in May 1986. Cover was least on field plots treated with lime and fertilizer (70%), and greatest on plots treated with the high rate of compost (90%) and high rate of sludge-compost mix (90%). The overall vigor of vegetation also was best in the latter two treatments.

Endomycorrhizae Development

In the greenhouse study, formation of endomycorrhizae in plants was enhanced by all rates of papermill sludge additions and by the two higher rates of the sludge-compost mix (54 to 98% incidence) as

Table 4.--Cumulative herbage yields of five harvests from greenhouse pot study.

Treatments and Rates	Hanging Rock Spoil			Weltzheimer Spoil		
	Ryegrass	Clover	Total	Ryegrass	Clover	Total
	(g/pot, ovendry)					
Control	1.07	0.16	1.23	0.03	0.00	0.03
Fertilizer & lime	5.39	8.13	13.52	5.72	6.52	12.24
Sludge 25[a]	6.31	5.94	12.25	6.84	10.11	16.95
Sludge 50	11.81	15.98	27.79	12.80	17.72	30.52
Sludge 75	16.48	12.96	29.44	16.77	15.94	32.71
Compost 25	8.23	21.19	29.42	11.07	29.73	40.80
Compost 50	15.53	27.84	43.37	13.83	37.73	51.56
Compost 75	20.82	18.94	39.76	19.08	39.09	58.17
Mix 25	6.85	16.39	23.24	6.39	28.39	34.78
Mix 50	12.66	35.53	48.19	11.51	37.31	48.82
Mix 75	17.00	38.09	55.09	16.42	43.85	60.27

[a]Rates are grams of sludge or compost added per 1,000 grams spoil (air-dry basis). Mix was half sludge and half compost.

Table 5.--Herbage yields in field plots at end of 1983 and 1984 growing seasons.

Treatments	1983	1984[a]
	(kg/ha, ovendry)	
Compost, high rate[b]	4,633	4,902
Compost, low rate	4,239	4,651
Mix, high rate	4,208	5,003
Sludge, high rate	3,269	5,883
Mix, low rate	2,375	4,267
Sludge, low rate	2,149	3,699
Lime & fertilizer[c]	1,906	1,915

[a] Includes current year's growth and previous year's residual plant material.

[b] High rate = 112 t/ha and low rate = 76 t/ha (air-dry); Rates for mixes were 56 (high) and 38 (low) t/ha of each material.

[c] Agricultural lime at 16 t/ha; 10-10-10 fertilizer at 560 kg/ha.

compared to the modest incidence of endomycorrhizae (27 and 28%) in the lime-fertilizer treatment. In contrast, formation of endomycorrhizae was inhibited in all pots amended with mushroom compost (0 to 7% incidence)(table 6). The relatively higher levels of Bray P_1 (plant-available) phosphorus in most of the compost-treated spoils (table 2) suggest that there may have been little need for VAM fungi to function in providing P to plants, thus accounting for their low incidence or absence. The higher incidence of VAM fungi at the lower levels of P_1 in the papermill sludge and mix treatments suggests that the VAM were functional and necessary in absorbing and providing additional nutrients to plants in those pots.

In the field, the incidence of endomycorrhizae was similar (50%) in plants collected from the lime plus fertilizer plots and mixed treatment plots. However, as observed in the greenhouse study, incidence of mycorrhizal formation in the field plots was adversely affected by mushroom compost additions (30%), but was improved with the papermill sludge amendments (90%). In fact, a far greater number of spores were produced by the external mycelium growing within small clumps of sludge dispersed throughout the rhizosphere than by mycelium growing in the rhizosphere soil alone.

Though no attempt was made to characterize the effect of the intrinsic properties of the amendments on microbial development, the consistent inhibitory effect of the mushroom compost amendment on endomycorrhizae formation may be related also to factors we observed in some preliminary tests with the amendments. A water extract of mushroom compost reduced germination of red clover seed by about 50 percent as compared to an extract of papermill sludge or distilled water. Chromatographic analyses of the water extracts of mushroom compost showed the presence of phenolic compounds, whereas none were detected for comparable extracts of papermill sludge. Though it appears that the high level of plant-available phosphorus was the primary factor limiting endomycorrhizae formation in the greenhouse pots where mushroom compost was used as the sole amendment, it is also possible that phenolic compounds present in the compost may have been involved. A number of studies cited by Melhuish and Wade (1985) have implicated various phenolic compounds in ectomycorrhizae inhibition.

Comparative Costs of Amendments

Where available close to potential areas of use, papermill sludge and mushroom compost may be viable alternatives to the application of lime, fertilizer, and

Table 6.--Incidence of vesicular-arbuscular mycorrhizal fungi in roots of plants grown in greenhouse pots.

Treatments and Rates	Hanging Rock Spoil	Weltzheimer Spoil
	-------(percent)[b]------	
Lime & fertilizer	27	28
Sludge 25[a]	96	77
Sludge 50	54	84
Sludge 75	95	98
Compost 25	7	7
Compost 50	0	0
Compost 75	0	6
Mix 25	37	43
Mix 50	85	85
Mix 75	87	86

[a] Rates are grams of sludge or compost per 1,000 grams spoil (air-dry). Mix was half sludge and half compost.

[b] Number of VAM observed per 100 root segments.

mulch for amending acid mine spoils. A major consideration in their use, however, is combined costs of material, transportation, and application. At the time of this study, the cost of these materials to be applied at 336 wet t/ha (112 air-dry) was $1,344/ha for papermill sludge and $2,016/ha for mushroom compost. Additional cost for application is estimated at $320/ha. Transportation of these materials is costly. The cost of hauling sludge or compost 80 km, as in this study for example, was about $1,500/ha or about as much as the material itself. Applying lime, fertilizer, and mulch at appropriate rates costs about $1,350/ha including materials, hauling, and application. Using conditions at the field study site as a basis for comparison, total costs are about $3,164/ha or 2.3 times greater for papermill sludge and $3,836/ha or 2.8 times greater for compost than for lime, fertilizer, and mulch ($1,350/ha). Herbage yields in the field plots (1984 clipping) amended with the organic materials at the 112 t/ha rate were 2.5 to 3.0 times greater than yields in the lime-fertilizer plots (table 5). Besides the greater early productivity, the beneficial longer lasting or residual effects on plant yield and vigor may also help compensate for the higher cost of using either papermill sludge or mushroom compost, or both as amendments for acid spoil.

CONCLUSIONS

Both the papermill sludge and compost materials used in this study were effective in amending acid mine spoils and promoting growth of herbaceous vegetation. Yields of vegetation in spoils amended with these materials were several times greater than in spoils amended with lime and fertilizer only, both in greenhouse and field studies. At application rates as low as 112 air-dry t/ha, both the sludge and compost seemingly provided adequate levels of plant-available nutrients for a longer period of time than did the mineral fertilizer.

Development of endomycorrhizae was inhibited in spoils amended with mushroom compost, but enhanced in spoils amended with papermill sludge as compared to the modest development in lime-fertilizer amended spoils. High levels of plant-available phosphorus and presence of phenolic compounds in the mushroom compost are probable causes for this inhibition of endomycorrhizae formation. How this inhibition of endomycorrhizae may effect vegetational productivity over the long term was not determined from this study.

The cost of applying papermill sludge, mushroom compost, or a mixture of the two can be several times greater than applying needed rates of lime, fertilizer, and mulch. Much of this cost difference may be attributed to greater transportation costs for sludge and compost. However, in this study, yields of vegetation also were several times greater in spoils amended with sludge or compost than in lime-fertilizer amended spoils. Thus, based on herbage production, the cost to benefit ratio is similar for both the organic and mineral amendments.

ACKNOWLEDGMENTS

The authors thank Charles (Ed) Adams of Mead Paper Corporation, Chillicothe, OH, and Nea Stockmeister Henry of N.E.A. Enterprises, Inc., Jackson, OH, for contributing organic amendments used in this study.

LITERATURE CITED

Allen, M. F. 1985. Spatial patterning and soil saprophytic microbiota: Impact of strip mining, importance and management strategies. In: Proc. 2nd Ann. Meet. Am. Soc. Surf. Min. and Reclam. October 8-10. Denver, CO. pp. 322-326.
http://dx.doi.org/10.21000/JASMR85010322

Cundell, A. M. 1977. The role of microorganisms in the revegetation of strip-mined land in the western United States. J. Range Manage. 30:299-305.
http://dx.doi.org/10.2307/3897311

Fresquez, P. R., and W. C. Lindemann. 1982. Soil and rhizosphere microorganisms in amended coal mine spoils. Soil Sci. Soc. Am. J. 46:751-755.
http://dx.doi.org/10.2136/sssaj1982.03615995004600040017x

Hoitink, H. A. J., and M. E. Watson. 1980. Reclamation of acid stripmine spoil with papermill sludge. In: Utilization of municipal wastewater and sludge for land reclamation and biomass production. U. S. EPA, Office Water Program Operations (WH-547), Washington, DC. pp. 301-306.

Hoitink, H. A. J., M. E. Watson, and P. Sutton. 1982. Reclamation of abandoned mine land with papermill sludge (Chapter 5). In: Neil Smeck and Paul Sutton (eds.) Abandoned Mine Reclamation Symposium. November 3-5, Ohio University, St. Clairsville, OH. 6 pp.

Mason, R. 1985. Shawnee NF restores toxic spoils with sludge. Contact. USDA FS (Eastern Region). Milwaukee, WI. March-April. 2 pp.

Melhuish, J. H., Jr., and G. L. Wade. 1985. Effect of soil phenolic compounds on growth and fatty acid composition of Pisolithus tinctorius. Trans. Ky. Acad. Sci. 46(3-4):129-133.

Phillips, J. M., and D. S. Hayman. 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Trans. Br. Mycol. Soc. 55:158-161.
http://dx.doi.org/10.1016/S0007-1536(70)80110-3

Schramm, J. E. 1966. Plant colonization studies on black wastes from anthracite mining in Pennsylvania. Am. Philos. Soc. Trans. N.S. 56 (Part 1): 1-94.

Shoemaker, H. E., E. O. McLean, and P. F. Pratt. 1961. Buffer methods for determining lime requirements of soils with appreciable amounts of extractable aluminum. Soil Sci. Soc. Amer. Proc. 25:274-277.

Sopper, W. E., and S. N. Kerr. 1979. Utilization of municipal sewage effluent and sludge on forest and disturbed land. Pa. State Univ. Press, University Park. 537 pp.

Vogel, W. G. 1981. A guide for revegetating coal minesoils in the eastern United States. USDA For. Serv. Gen. Tech. Rep. NE-68. Northeast. For. Exp. Stn., Broomall, PA. 190 pp.

Wilson, H. A. 1965. The microbiology of strip-mine spoil. W. Va. Agric. Exp. Stn. Bull. 506T, Morgantown. 44 pp.

http://dx.doi.org/10.2136/sssaj1961.03615995002500040014x