The Feasibility of Large-Scale Sewage Sludge/Compost Utilization on Central Appalachian Surface Mined Lands[1]

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Abstract The productivity of Appalachian mine soils is frequently limited by organic matter and associated low levels of fertility, aggregation and water holding capacity. Municipal sewage sludge has been used in various forms as a surface amendment in small plot studies in the Appalachian region, and results indicate it to be a superior soil treatment for long-term revegetation success. In April 1989, we initiated a large-scale research/demonstration project utilizing "mine mix" (wood chip compost + sludge cake from Philadelphia) as a surface amendment on a 150 ha active surface mine site in Wise County Virginia. The operation was permitted as a routine revision to a current mining permit. Between June and August 1989, approximately 26,000 wet Mg of mine mix were hauled to the site by rail and spread over the site at an average loading rate of 112 Mg/ha (dry weight as cake). The treatment was incorporated with a chisel plow to a depth of 20 cm. The mine soils were mapped at a scale of 1:3000 before sludge application, and the maps were then used to determine treatment areas, set-backs, hot spots and wetlands. Surface soils were sampled for lab analyses, and the average unlimed pH across the site was 5.7. An intensive water quality monitoring program over the period revealed no impact of the sludge application on surface or groundwater through January, 1990. This paper focuses on the environmental implications, regulatory framework, public relations, and logistical aspects of this project.

Additional key words: Water quality, nitrate movement, mine soil acidity.

Introduction

The successful long-term reclamation of mined lands is dependent on many factors; one of the most important is building and maintaining mine soil organic matter reserves. Recent research (Roberts et al., 1988a, 1988b) in the Powell River Project watershed in southwestern Virginia has demonstrated the superiority of municipal sewage sludge as a mine soil

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amendment. The mining industry faces serious financial and legal consequences if their reclamation efforts are not successful for a full five-year period after mining, allowing reclamation performance bonds (>$10,000 per acre) to be released. Local municipalities and waste water authorities also face an ever-growing cost of sludge disposal. Thus, the development of a mined land sludge utilization program would have obvious economic and environmental benefits for both the private and public sectors.

Despite the obvious advantages of sludge, the implementation of a sewage sludge utilization program on central Appalachian mined lands has been hampered to date by a number of factors. First, the region simply has not produced enough sludge in recent years to justify the economic and regulatory expense of developing, demonstrating, and monitoring an operational-scale sludge utilization project, or a regional mined land mapping/interpretive program. A second factor has been the dispersed nature of the region's treatment facilities, and a third factor has been the lack of carefully documented sludge trials on mined lands in this region. As a result of these factors and others, the protocols and technologies for the utilization of sewage sludge on southwest Virginia mined lands in an environmentally sound manner have not been developed.

We recently completed a five-year study of sewage sludge/plant growth dynamics (Roberts et al., 1988a) on southwestern Virginia mine soils which proved sewage sludge to be a superior long-term reclamation treatment. A major sewage sludge management firm, Enviro-Gro Technologies, indicated interest in the potential of this region for utilization of its "mine mix" sludge product. We have therefore executed a cooperative research/demonstration project among Virginia Tech, The Virginia Center for Innovative Technology (CIT), and Enviro-Gro to develop the necessary technologies and protocols for the environmentally sound use of municipal sewage sludge on Virginia mined lands.

Objectives

1. To evaluate the logistic, economic, and environmental feasibility of sewage sludge utilization on southwest Virginia mine lands through the development and monitoring of an operational-scale pilot project in the Powell River Project research watershed.

2. To carefully monitor the effect of sludge applications on long-term surface and ground water quality around the utilization area.

3. To determine optimal sludge application rates to insure reclamation success and protect environmental quality.

4. To develop a mined land classification and evaluation system for sludge utilization purposes.

5. To evaluate the potential mined land base in the Virginia coalfields that is suitable for sludge utilization.

Overall Approach and Cooperators

Considerable scientific research has been conducted to date on the interactions among sewage sludge, mine soil properties, plant growth, and environmental quality. Basically, we believe that as long as the sludge loading rate is appropriate, mine soil pH is maintained above 5.5, and water flow across the site is controlled, the advantages of sludge as a mine soil amendment far outweigh any potential adverse impacts. We have also completed exhaustive small-plot sludge studies on mined lands (Roberts et al., 1988a, 1988b) as have many others in the eastern United States (Sopper et al., 1982). Based on these combined findings, we felt that it was time to move ahead with a field-scale pilot utilization project, with research plots nested within the treated area, and adequate monitoring of the entire area to fully document soil/plant/sludge/water quality interactions.

An active surface mining operation (Red River Coal Co.) within the Powell River Project Research Area agreed to provide approximately 100 ha of newly reclaimed mine soils for the project. Of course, the full approval of the land owner (Penn Virginia Resources Corp.), the mining company, and the various regulatory agencies involved was required for such a venture to be successful. Penn-Virginia agreed in principle to the project, Norfolk-Southern Corp. agreed to haul the sludge compost for a reasonable rate, and Enviro-gro agreed to snpply and handle the sludge materials, and to support the research/monitoring effort. The Virginia Division of Mined Land Reclamation approved a permit revision by Red River Coal to substitute a compost/sewage sludge mixture for normal fertilization. This permit revision was also reviewed by the Virginia Water Control Board and the Virginia Department of Health.

The Powell River Project site is ideal for this type of research effort for a number of reasons. First, we have numerous detailed studies on the mine soils, water quality, and land resources within this area over a long period of time (Daniels and Amos, 1981a, 1981b, 1982; Roberts et al., 1988c). The overburden and mine soils in this area are some of the best in the Appalachian region, and are generally non-acidic. Second, due to the active mining operation in the area, we have good surface runoff control, and historical baseline water quality data from sediment ponds, wells, and streams surrounding the site. Third, we have been involved in a cooperative monitoring program at the active mining site, and know the exact composition and characteristics of the spoils across the site.

Materials and Methods

In order for applied research of this sort to be valid it must be conducted on a large enough scale so that we can truly evaluate the logistic and economic feasibility of handling large amounts of sludge materials in this rugged, remote terrain. For that reason we recommended that approximately 100 ha be the minimum pilot project area. An operation of this size allows us to observe and document the full-scale materials handling operations, and the effectiveness of the spreading techniques. It also permits us to determine the impact of full-scale compost/sludge application on both short- and long-term water quality in the surrounding sediment ponds, receiving streams, and groundwater.

Sludge Properties and Handling Procedures

The sludge material used for this project originated in Philadelphia, and was a 50:50 mixture of composted municipal sewage sludge (aerated static pile composting method) and stabilized anaerobic sludge cake. The average characteristics from 16 sieved samples taken in Philadelphia 1987 and 12 bulk samples taken in 1989 from the applied material are detailed in Table 1.

Table 1. Characteristics of Sludge "Mine Mix" Used in Study.

	1987	1989
	Sieved (< 0.7 cm)	Unsieved
pH	7.7	7.0
%Solids	53.00%	46.00%
Total N	1.90%	1.20%
Total P	1.70%	0.70%
Total C	28.00%	--
K	0.17%	0.30%
Mg	1.07%	.55%
Cd	11 ppm	3 ppm
Cr	133 ppm	--
Cu	425 ppm	294 ppm
Mn	317 ppm	455 ppm
Ni	53 ppm	73 ppm
Pb	213 ppm	159 ppm
Zn	749 ppm	562 ppm

The actual spread material is approximately two-thirds composted wood chips, and one-third partially composted sludge cake on a dry weight basis. The mix was shipped by Norfolk-Southern via rail. A total of 635 coal cars were used to haul the mine mix to Norton, Virginia. The material was unloaded from the rail cars using a Hertzog (tm) loader (Fig. 1), and transported to the site via covered truck. The trucks were tarped and brushed off before they entered the public road. The mine mix was stockpiled on the reclamation site and surrounded by berms of spoil until spread with specially designed sludge spreaders (Fig. 2).

The mine mix materials were incorporated by chisel plowing (20 cm) and heavy disking immediately after spreading, and were seeded immediately (Fig. 3). Sludge was not spread within five m of outslopes, drainage ditches, sediment ponds, etc. Equipment time was carefully documented in an effort to determine interactions among surface mine location, topography, cost of application, and the overall practicality of large-scale sludge application in these landscapes.

Based on our small plot work, and on experience elsewhere (Sopper et al., 1982) we assumed that an average rate of 112 Mg/ha (as sludge) could be effectively incorporated into these spoils. Our actual average loading rate was approximately 100 Mg/ha as sludge, along with about 200 dry Mg of composted wood chips. We ran trials at the onset of spreading operations to verify this assumption. A replicated (four) loading rate study was installed during the spreading operation as discussed below. We sub-sampled the materials just before application for analysis and calculation of total loading rates.

Figure 1. The "mine mix" materials were unloaded from coal cars using specialized front-end loaders into haul trucks. Care must be taken in the selection of unloading facilities and hauling routes to avoid adverse public reaction.

Description of Long-Term Research Program

Before the sludge was applied, we mapped the mine soils of the entire area in detail. This will allow us to determine the interactions of sludge and mine soil type over time. Every year, we will sample and analyze the standing vegetation throughout the treated area. We will concentrate on intensive soil and plant tissue sampling and analyses from research plots nested within the treated area. In these replicated plots we varied the sludge loading rates from 0 to 175 dry Mg per ha. Soil and plant tissue samples will be taken annually and analyzed for all plant macro- and micro-nutrients and all heavy metals of environmental concern. Additional soil-plant analyses will be performed as agreed to or specified by the regulatory agencies involved.

We are particularly interested in the influence of sludge on the more acidic spoil materials, since considerable research has indicated that it will buffer pH, and reduce iron and manganese availability. While the vast majority of spoils within this area are non-acidic, the operator does face a pre-existing acid discharge problem from previous mining activities, and some limited areas of acid spoils will be delineated and treated for the sake of the research effort.

One of the major concerns associated with large-scale sewage sludge utilization programs is the potential contamination of surface and groundwaters, particularly by nitrate. Our water quality monitoring program is cooperative with, and in some cases in addition to, the regular monitoring program that Red River Coal carries out on the permit. Sediment ponds are sampled weekly, groundwater wells biweekly, and surface water instream sites monthly. A total of 12 sites are currently being sampled, and more will be added as mining is completed over the next year. A broad range of parameters have been analyzed at each location including pH, hardness, acidity and alkalinity, total-Fe and Mn, heavy metals, C, P, NO_3^-, and SO_4^{2-}.

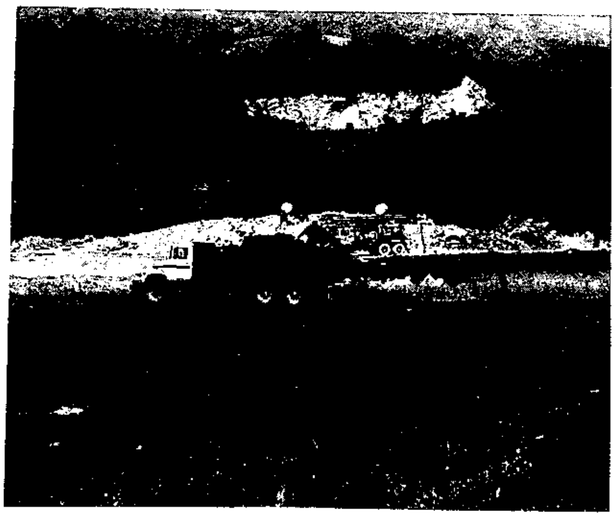

Figure 2. The "mine mix" was applied by either spreader truck as shown or with a spreader unit pulled behind a farm tractor. The total loading rate was 350 wet tons per acre of mix, or 112 Mg/ha as sludge cake. The depth of the material was approximately 12 cm before deep incorporation.

Results and Discussion

Over the course of the summer of 1989, approximately 26,000 wet Mg of the mine mix product were applied to approximately 40 ha of the site. All incorporation for the 1989 season was completed by late October, and the area was seeded to a conventional hayland-pasture mix with a winter rye cover crop. The balance of the sludge was stockpiled, to be spread the following spring (1990). During this period of time we learned quite a bit about the logistics, mechanics, and potential pitfalls of large-scale sludge application and utilization in this kind of landscape. The balance of this paper will address our first-year findings and insights.

Mine Soil Mapping and pH

Before sludge application, we mapped all areas at a scale of 1:3000 on standard black and white aerial photos. Contrasting mine soils were delineated based on rock type composition, slope class, depth to hard rock, wetness, and surface configuration. Further detail on the mapping criteria employed is given by Daniels and Amos (1981a, 1981b). These maps were then used to calculate the amount of suitable area across the site for sludge application. We found that mapping at this scale was essential to accurately delineate suitable treatment areas, isolate hot spots and wetlands, and delineate varying slope or roughness classes. We evaluated the use of larger scale (1:4800 and 1:6000) imagery for the site-specific mapping, but found it generally inadequate.

Since the total mined area was fairly large, we subdivided it into "treatment cells" which were labeled alphabetically, and the exact area of each cell was determined with an acreage grid. Large bulk samples of the mine soils were taken on a 50 m grid across the entire area to a depth of 15 cm. These samples were taken before sludge application, and will be taken every year thereafter for characterization of chemical, physical and mineralogical properties. The average soil pH of the areas treated in 1989 is given in Table 2.

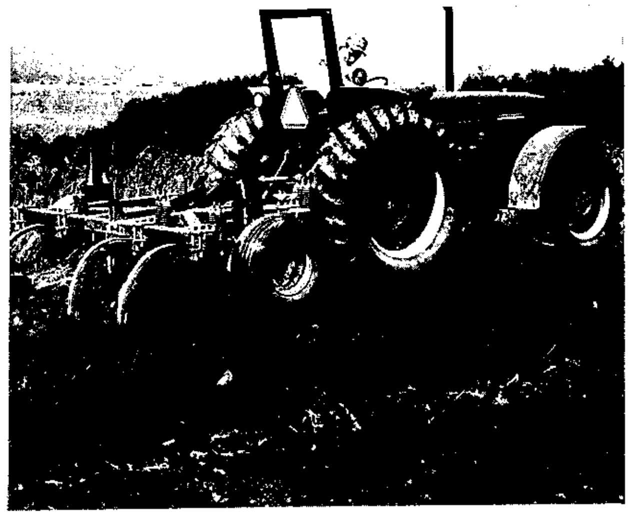

Figure 3. The material was incorporated with a chisel plow to approximately 20 cm+, and then disked with a heavy off-set disk. A hayland/pasture seeding mix was broadcast over the site after the final disking.

The majority of overburden mined at this site is non-acid-forming, and tends to stabilize at pH values above 5.0. However, areas do exist across the site which contain varying amounts of acid-forming materials. These range in size from several hectares to several meters in diameter. The average pH values for areas D and F were pulled down by several very acidic hot spots which were sampled intentionally for characterization, while the pH of area E was uniformly low. Area E was limed at a rate of 10 Mg/ha prior to sludge application, and all hot spots within the entire application area were spot limed at a similar rate. We will continue to monitor soil pH across the site over time, but do not expect overly acidic conditions to develop. Soil pH will be maintained above 5.5 by liming if necessary.

Water Quality Monitoring and Treatment Effects

Our water quality monitoring program will need to continue for several years before the long-term influence of the sludge treatment can be adequately assessed, particularly the potential deep movement of nitrate to groundwater. The summer of 1989 was one of the wettest on record, however, and we were encouraged by the fact that under exceptionally heavy rainfall conditions we did not detect any surface run-off of sludge-related contaminants from stockpiles or spreading areas (Table 3).

Table 2. Average soil pH before application of sludge for various sites.

Area	# of Samples	Average pH
A	10	5.65
B	13	5.96
C	19	5.81
D	21	5.24
E	7	4.65
F	8	5.18
G	5	5.42

The total-N loading applied to this area was quite high in an effort to supply organic matter and plant nutrients for the five-year bond release period and beyond. However, the overall C:N ratio of the material is above 20:1 due to the large component of wood chips, and we do not anticipate major nitrate leaching. Other mined land work in Pennsylvania (Sopper et al., 1982) with heavy loading rates has shown minimal or no off-site movement of nitrogen. We believe that large amounts of the total-N loading will also be lost via volatilization and denitrification pathways, and we will attempt to verify this hypothesis. We also believe that the moderate native pH of these spoils will limit any potential heavy metal uptake into plant tissue. Again, we will verify this assumption over time.

Logistical Concerns

The concept of using empty railroad cars to back-haul sludge materials from urban areas to the coalfields is certainly attractive, but is not without its pitfalls. First, the waste treatment site must have a rail siding adequate for loading the sludge into rail cars; many do not. Second, an adequate siding must be located within a relatively short hauling distance of the application site, and it must be large enough to allow for many cars to be processed without interfering with normal coalfield traffic. We incorrectly assumed that sidings associated with coal prep plants near our site would be adequate for this function, but they were not large enough to handle our traffic without affecting coal traffic to and from the tipple. The siding we finally used was associated with an old coal crushing facility approximately seven miles from the site, and was not an ideal location. The loading operation in Philadelphia was capable of filling approximately 15 cars per day, which were combined into units of 40 or more and shipped in batches. This process, combined with normal delays in shipment and bad weather made it difficult to coordinate the short-haul trucking to the site with any regularity. For this and other reasons, the short-haul trucking accounted for almost one-third of the total cost of transporting the materials. Despite these difficulties, between June 6 and August 25, we were able to completely move 635 rail cars of material to the site. The total cost of transportation is proprietary information at this time, but the costs did fall within the expected range of the sludge management firm involved (Enviro-Gro Technologies).

Table 3. Levels of nitrate, pH and total iron at 3 water sampling locations typical of the project area. Site GW-2 is discharge from a hollow fill, Pond 2 is a large sediment pond which receives surface drainage, and the Powell River location is just downstream from the treatment area, on a major perennial stream draining the site. All values are a mean of 5 observations.

	------sampling date (1989)------				
Location	Pre-Sludge	Jun	Jul	Aug	Sep
	----- NITRATE (PPM) ----				
GW-2	4.35	2.34	1.88	2.29	2.21
Pond 2	1.92	2.19	1.71	1.73	1.20
Powell R.	nd	0.58	1.80	nd	--
	----------- pH -----------				
GW-2	6.5	6.6	7.5	7.4	7.0
Pond 2	6.9	6.8	7.4	7.4	7.6
Powell R.	6.8	7.5	7.5	--	--
	----- TOTAL-FE (PPM) -----				
GW-2	1.9	--	0.2	0.7	0.6
Pond 2	0.6	0.8	0.6	0.2	0.2
Powell R.	0.7	0.5	0.1	--	--

By mid-June 1989, sufficient sludge had been hauled to the site for application procedures to begin. The spring and summer of 1989 were very wet, however, and the imperfectly drained benches would not support the spreading vehicles for a large part of the summer. This experience pointed out the great importance of detailed mapping, particularly the accurate delineation of seasonal wet spots and ephemeral drains. Once the benches dried sufficiently to support spreading operations, up to 1,000 wet tons of mine mix could be spread per day (Fig. 2).

Incorporation was completed much more quickly than the spreading, and the areas usually received two to three passes with the chisel plow (Fig. 3), and two passes with a heavy off-set disk. A 4WD 85 horsepower tractor was used for incorporation operations. Through experimentation, we found that the mine mix could be spread and incorporated on up to a 15% slope on highwall backfills, and down slopes in excess of 20% when equipment could be driven to the top of a fill slope and then down.

Public Relations and Regulatory Issues

The land application of sewage sludge

materials is often controversial, regardless of the locale of operations. Despite the fact that this project was heavily publicized in the media, several citizens along the direct-haul truck route were not aware of the project until the actual unloading and hauling began. These individuals became quite irate and complained vigorously to all regulatory agencies involved. Interestingly enough, the citizens were not nearly as concerned about the environmental and water quality implications of the land application program as they were about human health issues such as the potential for AIDS transmittal. Obviously, in order for such a research-demonstration operation to be successful, the local community must be completely informed of the objectives, methods, and safeguards employed. Beyond these measures, however, we also recommend that great efforts be made to keep all unloading and hauling away from public roads whenever possible.

From a regulatory perspective, there are obvious advantages to incorporating sewage sludge utilization into active mining permits since the mining agencies generally have jurisdiction over NPDES discharge permits and other water quality programs. The routine sampling associated with the water quality monitoring program for an active permit can be easily modified to include nitrate and other parameters of interest such as heavy metals. However, this is not the case wheu sludge is used as a treatment on abandoned or bond-released mined lands. In this instance, a "conventional" sludge application permit must be obtained through the relevant state agencies, and the cost of permitting and monitoring is much higher. It should also be noted that currently proposed EPA regulations for land application of sludge materials could severely limit the loading rate to mined lands, and would severely affect the economics of operations such as this.

Conclusions

Based on our experience with this project, we believe that the widespread use of municipal sewage sludge materials is logistically and economically feasible in this region. Detailed mapping and characterization of the site before application are essential to correctly specify the total suitable acreage, and to identify areas which will pose limitations to spreading equipment. To date, no influence of the sludge application effort has been detected in ground or surface waters around the site, but long-term monitoring is essential for a project such as this. Additional monitoring of soil and plant tissue nutrient and heavy metal levels must be continued for multiple seasons before the overall environmental impact of the treatment can be adequately assessed. If the sludge is to be back-hauled to the site in rail cars, careful attention must be paid to the development of an adequate unloading facility which is as close to the spreading site as possible. Hauling on public roads should be avoided whenever possible, and local citizens must be kept constantly informed of project objectives, methods, and monitoring efforts.

The implementation of full-scale sewage sludge utilization on southwest Virginia mined lands could lead to markedly improved reclamation and associated improved local water quality. The use of sewage sludge will provide an immediate financial benefit to the mining industry through reduced fertilizer, lime, and reseeding costs, and a significant long-term economic benefit through greatly enhanced probability of timely release of reclamation performance bonds. The project will also be of great value to the expanding sludge utilization industry. Furthermore, the completion of this effort will supply local waste water authorities with an economically viable alternative for the use of their sludges.

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