MINE SPOIL RECLAMATION WITH SEWAGE SLUDGE STABILIZED WITH CEMENT KILN DUST AND FLUE GAS DESULFURIZATION BYPRODUCT (N-VIRO SOIL PROCESS)[1]

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Abstract: Research in recent years has shown that organic wastes such as sewage sludge, sludge compost, livestock manure and others can be used to enhance reclamation of drastically disturbed lands, particularly acidic mine spoils in the eastern U.S. (Sopper, 1992; Logan, 1992; Hossner and Hons, 1992). These materials primarily provide nutrients and organic matter, and have to be supplemented with lime applications for reclamation of acid spoil. A new patented process, the N-Viro Soil technology, which is classified by U.S. EPA as a Process to Significantly Reduce Pathogens (PFRP), uses alkaline admixtures to pasteurize and stabilize dewatered sewage sludge (Burnham et al., 1990). The process results in a dry, granular product that contains limestone, nutrients and organic matter (Logan, 1990). The combination of "soil-like" physical properties and lime, nutrients, and organic matter make N-Viro Soil an excellent material for use in reclamation of acidic mine spoils. Of equal significance is the recent finding that one of the alkaline materials that can be used in the N-viro Soil process is flue gas desulfurization byproduct (FGD), produced by electrical generators in the scrubbing of SO_2 from high sulfur coal. The potential, then, is to combine two waste materials, sewage sludge and FGD, into an environmentally acceptable and valuable product.

In this paper, I will briefly review the N-Viro Soil process, summarize important physical and chemical properties of N-Viro Soil produced with cement kiln dust (CKD) and with FGD, and use of the CKD product in a greenhouse study to reclaim abandoned mine spoil (pH < 3); plans for a large field study with a FGD product on reclamation of acidic mine spoil are discussed.

The N-Viro Process

The N-Viro process is summarized in Figure 1. The basis of the process is to destroy pathogens through a combination of the following stresses: 1) Alkaline pH; 2) Accelerated drying; 3) High temperature: 4) High ammonia; 5) Salts; 6) Indigenous microflora. Raw primary, activated sludge, or digested sludge with solids content of 18-40% is used. Sludge, CKD, other alkaline reagents, and other additives are mixed with a pug mill or screw blender. If the alkaline reagent contains enough lime (CaO, $Ca(OH)_2$ or other strong alkali) to give a pH rise to > 12, and an exothermic reaction necessary to achieve desired temperature (52-62° C), no other additive is needed. CaO is added to supplement the free lime content of the alkaline reagent if it is not "hot" enough. The ratio of alkaline reagent to sludge solids varies primarily with the solids content of the sludge, with a higher ratio being used for sludges with lower solids content. With proper mixing speeds, the resultant product is a granular, easy-to-handle soil-like material that is further processed by one of two methods: Alternative 1 or Alternative 2.

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Alternative 1

The sludge/alkaline reagent mixture is air dried while the pH remains above 12.0 for at least seven days. The N-Viro Soil must be held for at least 30 days and until solids content is at least 65% by weight. Ambient air temperatures during the first seven days of processing must be above 5^0 C.

Alternative 2

The sludge/alkaline reagent mixture is heated while the pH exceeds 12.0 using exothermic reactions from the alkali, if required. Temperatures must be 52^0 C throughout the mixture. The material must be stored in such a way (e.g., in a bin) so as to maintain uniform minimum temperatures for at least 12 hours. Following this heat pulse, the N-Viro Soil is air dried (while pH remains above 12.0 for at least three days) by windrowing until the solids content is > 50% by weight. This alternative has no ambient air temperature requirements.

The N-Viro Soil process is an EPA-approved PFRP process. Not only does it rapidly destroy pathogenic bacteria and viruses, but effectively kills Ascaris ova, the most resistant of sludge pathogens. Ascaris eggs are reduced to < 1 per 5 g sludge within 6 hours.

An important characteristic of N-Viro Soil is its ability to reduce sludge odors rapidly and to maintain a stable, odor-free product with prolonged storage. Initial odor control is achieved by the large surface area provided by the fine grained alkaline reagent, the rapid drying which occurs with windrowing, and pathogen kill. Long term odor control is maintained by the continued degradation and stabilization of organic sludge solids by the remaining heterothrophic soil microorganisms.

Characteristics of N-Viro Soil

General characteristics of N-Viro Soil are summarized in Table 1. Of significance for reclamation are its high $CaCO_3$ equivalency, soil-like physical properties, and relatively balanced nutrient content. Logan et al. (1989) have shown that about 20% of the TKN is mineralizable in the year of application. In addition, Bennett (1989) showed that, even when the pH of the material was reduced to 5 by acid pretreatment, EP/TOX leachable metals were greatly reduced compared to metal leaching from the sludge itself. N-Viro Soil has a high initial pH that is controlled by the residual strong alkali ($Ca(OH)_2$) in the material; $Ca(OH)_2$ is more water soluble than $CaCO_3$ and will control the pH in water. The overall pH buffering is controlled by the $CaCO_3$, and will have found that the pH in soil drops rapidly (Figure 2). Soil reaction can be predicted accurately by adjusting lime requirements for $CaCO_3$ equivalency.

Use of N-Viro Soil for Abandoned Mine Spoil Reclamation

Methods and Materials

A Greenhouse study was conducted to evaluate the use of N-Viro Soil to revegetate acidic abandoned mine spoil from eastern Ohio (Prexotto and Logan, unpublished date). Mine spoil was collected from the Moxahala Creek abandoned mine reclamation project in Perry County. The material had a 1:1 H_20 pH of 2.9; Bray P1 available P of < 2 kg/ha; exchangeable CA, MG and K of 210; 147 and 44 kg/ha, respectively; CEC was 18 $cmol_c/kg$ and CA, Mg and K base saturations were 3, 3 and 0.3, respectively. The N-Viro Soil used in the study was made from City of Toledo waste activated sludge and CKD was the alkaline reagent. Characteristics of this material are summarized in Table 2. The experimental design consisted of N-Viro Soil at rates of 50, 100 and 200 mt/ha equivalent; and NPK fertilizer and $CaCO_3$ at rates equivalent to that in the N-Viro Soil, assuming that 20, 50 and 100% of the TKN, P and K in the N-Viro Soil are available and that the material contains a $CaCO_3$ content of 88% (Table 2). N, P and K were applied as $Ca(NO_3)_2$, $Ca(H_2PO_4)_2$, and KCl. Four replicates of each treatment were prepared by mixing the spoil with the amendments and placing 9 kg of each mix in pots. Pots were wet until saturated, allowed to drain freely, covered with plastic film and incubated for a week. After incubation, the

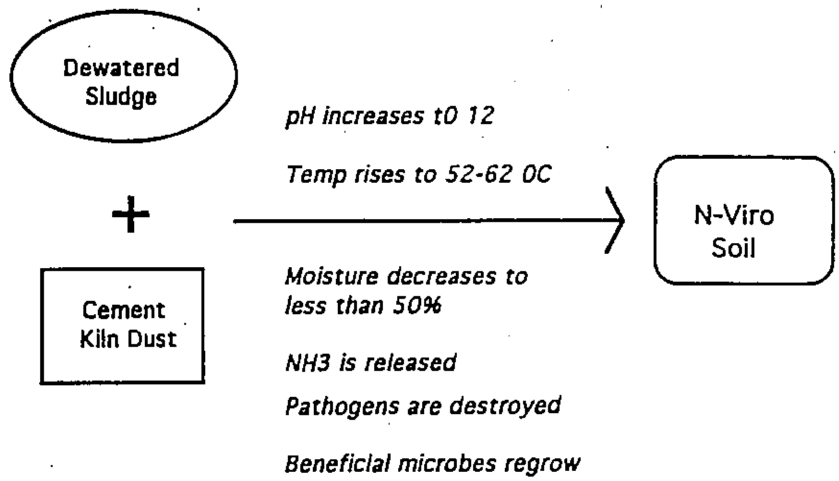

Figure 1. Basic reactions in the N-Viro process.

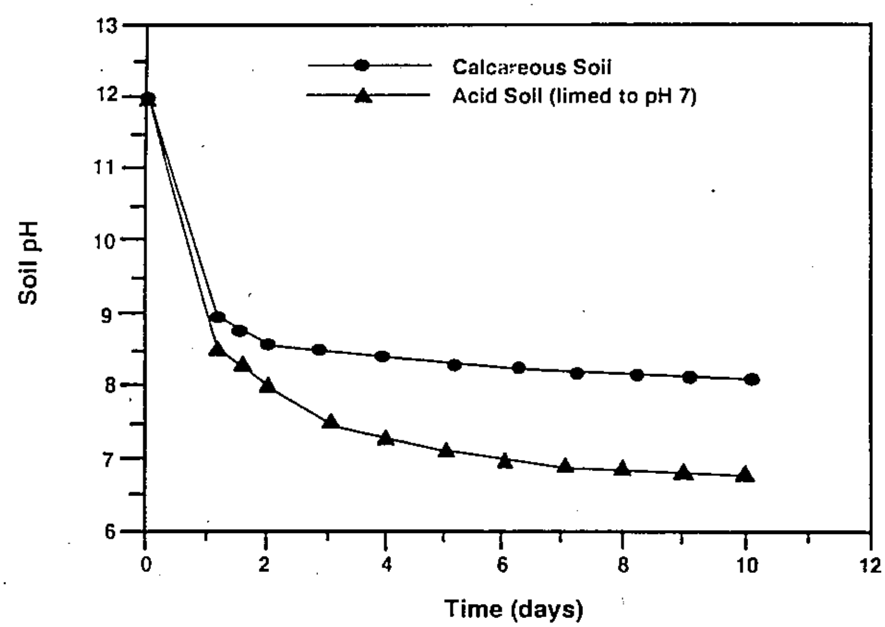

Figure 2. Rate of change of soil pH with application of N-Viro Soil.

Table 1. General characteristics of N-Viro Soil (Logan, 1990)

Characteristic	Units	Value
CKD content	% by wt.	35-75
Solids content	% by wt.	50-75
Material > 2 mm	% by wt.	32
Mean granule size	mm	0.66
Bulk density	g/cm^3	0.7-1.0
Volatile solids	% by wt.	9.3
pH (1:1 water)		11-12
$CaCO_3$ equivalent	% by wt.	50-80
Organic-C	% by wt.	12.2
Total Kjeldahl N (TKN)	% by wt.	1-1.5
NH_3-N	mg/kg	200
NO_3-N	mg/kg	50
P	% by wt.	0.39
K	% by wt.	1.0
Ca	% by wt.	20
Mg	% by wt.	1.0
Na	% by wt.	0.2

pots were seeded with a reclamation mixture of annual ryegrass, orchard grass and birdsfoot trefoil. After 89, 155 and 182 days, the plants were harvested, dried and weighed. The roots were separated from the soil by washing, dried and weighed. Plant material was digested and analyzed for N, P, K, Ca, Mg, Al, Cu, Fe, Zn, Na, and Mn. Samples of the soil were analyzed for pH, organic-C, TKN, and total P, K, Ca and Mg. Selected results will be presented.

In a separate component of the study, 1 kg of each treated spoil mixture was placed in a plastic bag and wet to 20% H_20 by wt. The sealed bags (opened periodically for air exchange) were placed in the greenhouse next to the pots, incubated and samples removed at intervals of 1, 4, 8, 16 and 24 weeks. The samples were water saturated for 24 hours and the soil solution was then removed by centrifugation and filtration. The filtration was analyzed for pH, EC, total C, total organic C, CI, SO_4, NO_3, PO_4, Ca, Mg, and K. All analyses were made with standard procedures and on duplicate samples. Selected results will be presented.

Results and Discussion

Above-ground and root biomass are presented in Figure 3 for N-Viro Soil and lime and fertilizer (LF) equivalents. N-Viro Soil and LF gave similar above-ground biomass responses as predicted, but N-Viro Soil as 200 mt/ha have greater root biomass than LF.

Chemical composition of the above-ground biomass is presented in Figure 4 for the 89 day cutting. The results for the 155 and 182 day cuttings were generally similar and are not presented. Nutrient levels were similar for the N-Viro Soil and LF treatments and there were no significant differences between the two sources. This suggests that the assumptions made as to nutrient availability in the N-Viro Soil are reasonable. Aluminum levels were higher with N-Viro Soil than with LF, particularly at the highest rate. This could have been due to the very high initial pH of the amended spoil with the 200 mt/ha N-viro Soil treatment (see below); Al solubility increases at alkaline pH due to the formation of $Al(OH)_4$- in solution. Zinc and B concentrations were also higher with N-Viro Soil; significant amounts of Zn were added with the N-Viro Soil (Table 2), and, although B content of the N-Viro Soil was not determined, it was probably high enough to increase the levels relative to the unamended spoil. None of the levels of trace metals studied were considered to be excessive (Adriano, 1986).

Analysis of the soil solution showed that all of the lime treatments raised pH in the range of 7.5 (Figure 5) while the N-Viro Soil treatments gave initial pHs that ranged from 11 to 12.5, decreasing to about 8.5-9 with time. This suggests that there was an excess of $CaCO_3$ in the lime treatments to buffer pH, while the decrease in pH with the N-Viro Soil confirms that rapid neutralization of the $Ca(OH)_2$ alkalinity with eventual buffering by $CaCO_3$. The rate of pH decline was slower than observed for soils (Figure 2), probably because of the low exchange capacity and coarse particle size of the spoil.

A major difference in soil solution composition between the LF and N-Viro Soil treatments was in dissolved organic C (DOC) content (Figure 6). Levels in the LF treatments were < 5 mg/L, typical of concentrations found in mineral ground water environments. Initial DOC in the N-Viro Soil treatments ranged from 200 to 600 mg/L, generally declining with time, presumably as a result of microbial decomposition. There are several consequences of this finding. On a positive note, movement of DOC into the subsoil of mine spoil environments could increase biological activity and help to stimulate root growth as was observed in this study (Figure 3). DOC could also complex potentially toxic trace metals. On the other hand, high levels of DOC stimulate denitrification and this could results in reduced available N levels. In fact, nitrate-N levels in the N-Viro Soil treatments were < 1 mg/L compared to concentrations of 100-600 mg/L with the fertilizer treatments. Nevertheless, N levels in plant tissue (Figure 4) were similar for the two treatments.

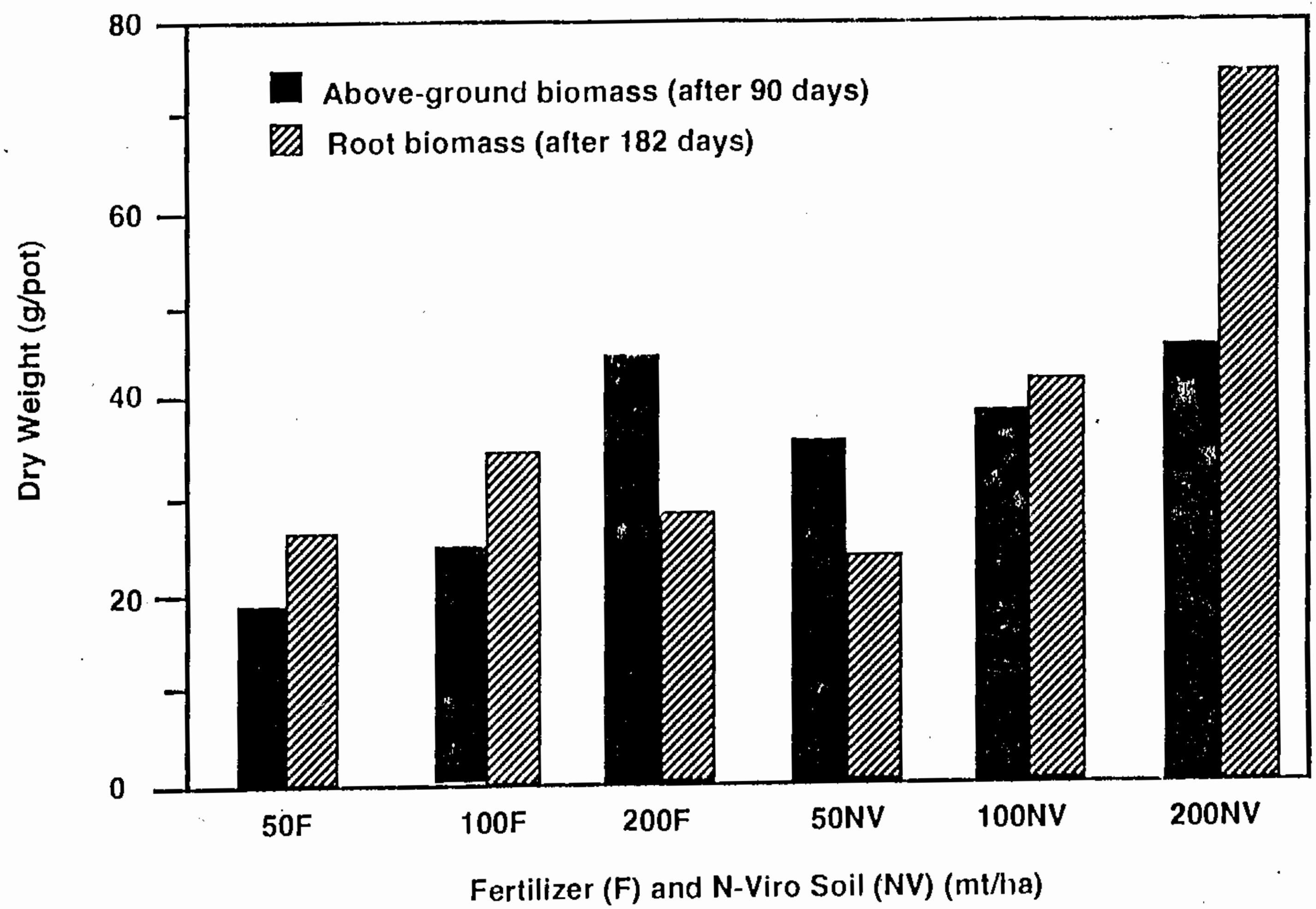

Figure 3. Above-ground and root biomass of grass established on acidic coal mine spoil treated with N-Viro Soil or equivalent amounts of lime and fertilizer.

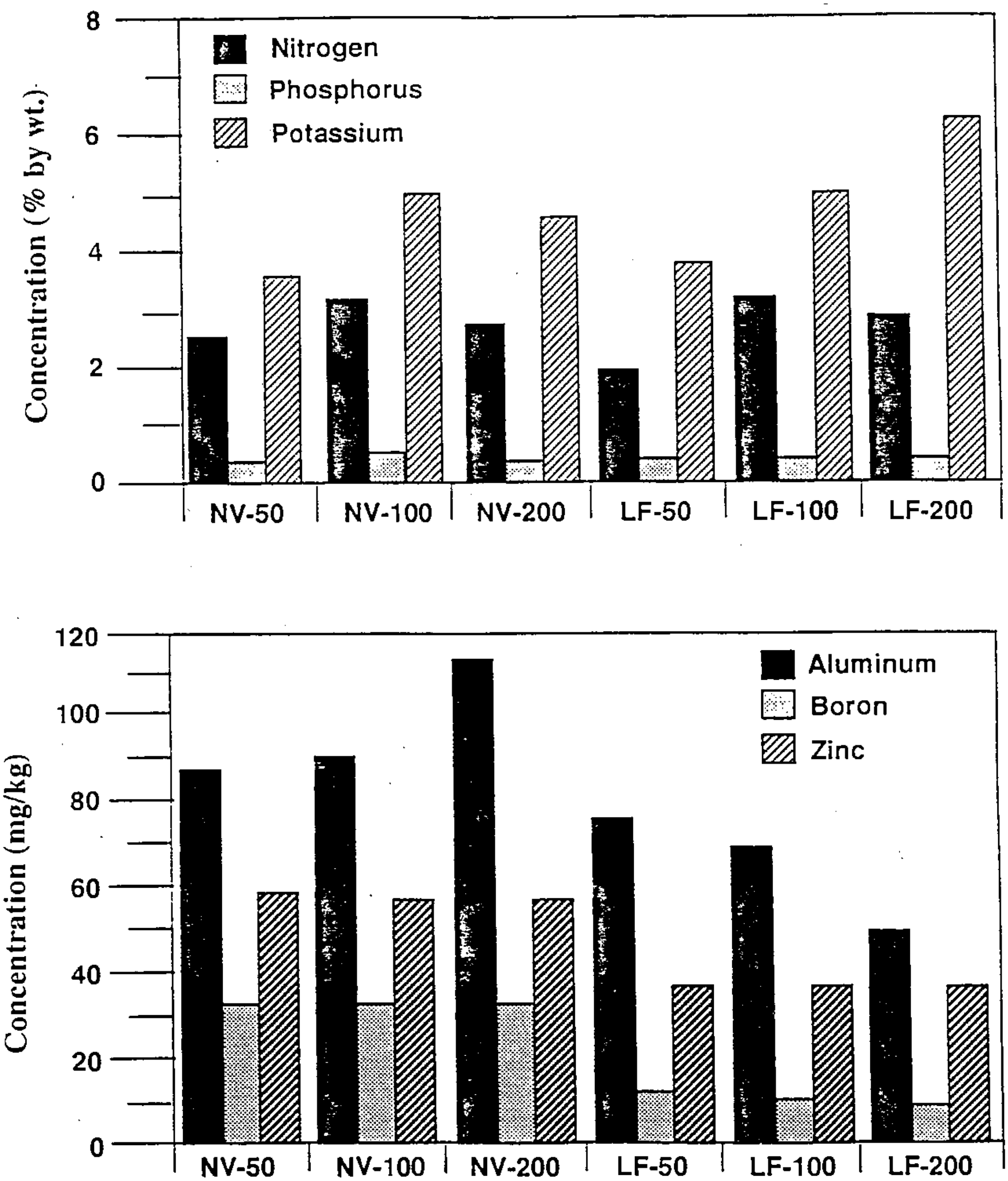

Figure. 4 Chemical composition of grass established on acidic coal mine spoil treated with N-Viro Soil or quivalent amounts of lime and fertilizer.

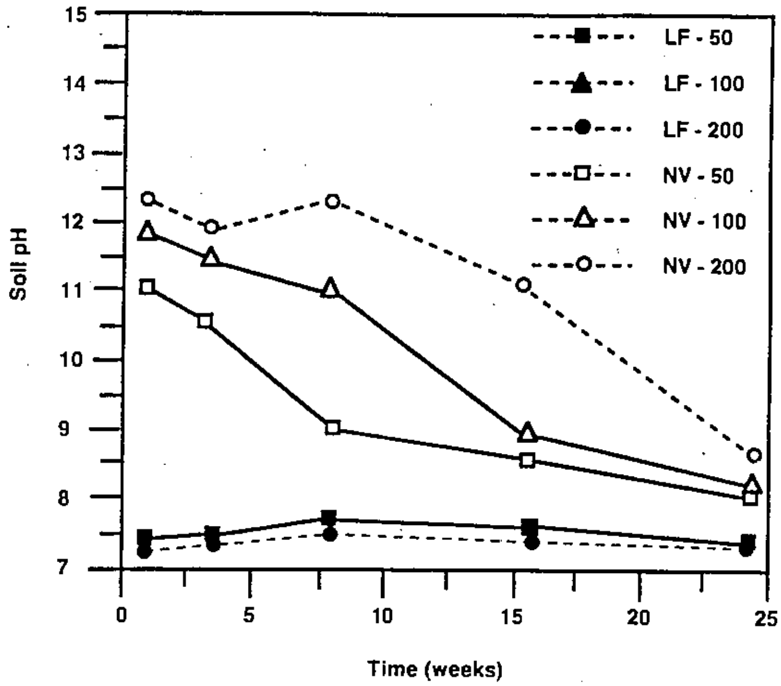

Figure 5. Changes in soil solution pH in acidic coal mine spoil treated with N-Viro Soil or equivalent amounts of lime and fertilizer.

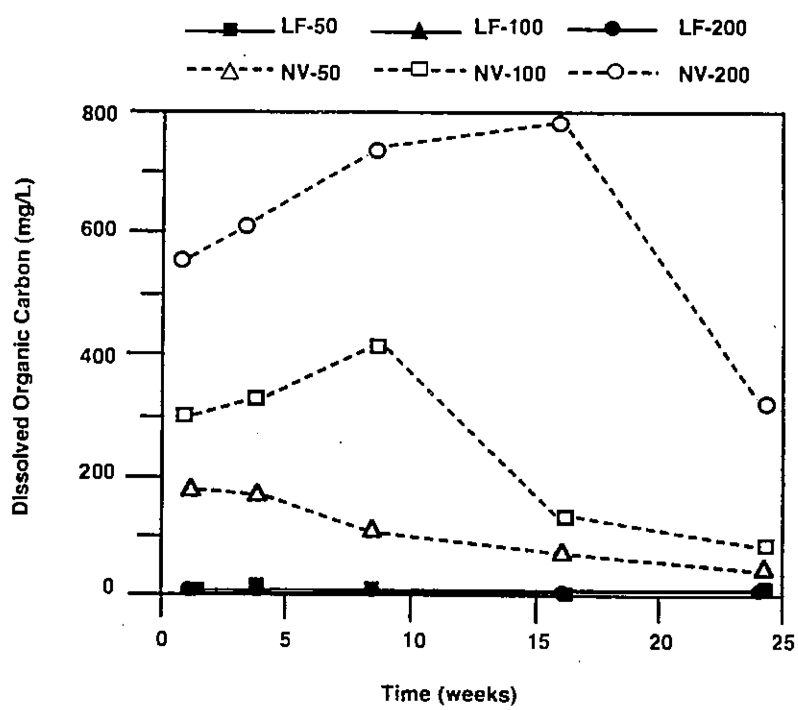

Figure 6. Changes in soil solution dissolved organic C in acidic coal mine spoil treated with N-Viro Soil or equivalent amounts of lime and fertilizer.

N-Viro Soil Produced From FGD

Flue gas desulfurization (FGD) byproducts are produced as a result of new technologies for removal of SO_2 emissions from burning of high-S eastern coals. The various technologies result in material of varying chemical composition and physical characteristics, but generally consist of physical and chemical mixtures of fly ash, gypsum and unreacted lime (CaO) or limestone ($CaCO_3$). One of these technologies is the lime injection multistage burner (LIMB) process. It has been used in a full scale demonstration at a coal-fired, 105 megawatt boiler at Ohio Edison's Edgewater plant. The process involves injection of lime as a finely atomized mist into the upper part of a suspension-fired boiler where it reacts with SO_2 at temperatures ranging from 2,000 to 2,300^0 F. About 150 to 250 dry tons of FGD are produced daily at this plant. Nationwide projections for production of FGD as power plants adopt these technologies are in the millions of dry tons annually. Of concern is how to efficiently utilize this byproduct in an environmentally acceptable manner. As part of a larger project, funded by the Ohio Coal Development Board, Dravo Lime Company, and DOE, investigating beneficial reuse of FGD, exploratory research was conducted to determine if the LIMB FGD could be utilized as an alternative alkaline reagent in the production of N-Viro Soil.

Samples of LIMB FGD were tested by N-Viro Energy Systems, Inc. and were shown to produce the heat and pH rise specified in the N-Viro Soil process. Analysis of the resulting product is summarized in Table 3. Values are generally in the range observed for other N-Viro Soil materials (Table 1). Samples of the N-Viro Soil and the LIMB FGD were extracted with water (20:1 H_20 to solid, 18 hr) and the N-Viro Soil was also subjected to the EP/TOX leaching extraction with pH 5 acetic acid used for the analysis of potentially hazardous wastes. Analyses were performed by ICP in the Agronomy Department, Ohio Agricultural Research and Development Center, Wooster, Ohio. Results are given in Table 4. Concentrations in the EP/TOX and water extracts of N-Viro Soil were similar in most cases; major differences were in Mg and Si which were much higher in the EP/TOX extract. The final EP/TOX extract pH of 7.41 is not that different from water and resulted from neutralization of the acetic acid by the residual alkalinity in the N-Viro Soil. The free acetate ligand would have mobilized some metals, enough to account for the observed differences. There were few major differences in water extractable elements between the LIMB FGD and N-Viro Soil, and these were predictable. The LIMB FGD contained more total S and sulfate, and B, elements normally associated with these materials, while the N-Viro Soil contained more K, Na, P, Ni, Cu, Zn and F, all normally found in sewage sludges.

The results of these analyses suggest that the LIMB FGD-produced N-Viro Soil can be safely used as a soil amendment, and several field studies were conducted in 1992 to test this material. In the first study, the material described here will be used to revegetate previously mined areas in eastern Ohio at a rate of about 100 mt/ha. Observations on plant growth will be made. In the second, more comprehensive study, N-Viro Soil produced with Toledo sludge and FGD to be specified later will be used to reclaim an abandoned mine spoil site near Dover, Ohio in conjunction with the Ohio Department of Natural Resources Abandoned Mine Reclamation Program. N-Viro Soil will be applied at a rate of approximately 200 mt/ha to paired watershed of approximately 1-ha size; another set of paired watersheds will receive lime and fertilizer as amendments for comparison. The watershed will be instrumented with flumes and subsurface monitoring equipment to monitor and sample surface and ground water for chemical analysis. Vegetative growth will also be monitored. Smaller, replicated plots will receive similar treatments and a portable rainfall simulator will be used to determine changes in erodibility of the reclaimed surface following treatment and revegetation.

Table 2. Characteristics of the N-Viro Soil used in the reclamation study.

Parameter		Units	Value
Water content		% by wt.	50.1
pH (1:1 H_2O)			12.5
$CaCO_3$ equivalent		%	88.4
TKN		% by wt.	0.5
Total	P	% by wt.	0.24
	K	% by wt.	0.89
	Ca	% by wt.	33.4
	Mg	% by wt.	11.1
	Cd	% by wt.	4.8
	Cu	% by wt.	49.9
	Ni	% by wt.	478
	Zn	% by wt.	262
	Cr	% by wt.	599
	Pb	% by wt.	1350
	Mn	% by wt.	166

Table 3. Analysis of N-Viro Soil using Toledo sludge and FGD as the alkaline reagent.

Parameter		Units	Value
Solids		% by wt.	54.1
Bulk density		g/cm^3	1.32
$CaCO_3$ Equivalent		%	29
TKN		% by wt.	0.57
NH_3-N		% by wt.	0.26
Total	P	% by wt.	0.78
	K	% by wt.	0.09
	Ca	% by wt.	14.7
	Mg	% by wt.	0.59
	B	mg/kg	150
	Cd	mg/kg	3.6
	Cu	mg/kg	130
	Pb	mg/kg	73
	Mn	mg/kg	180
	Ni	mg/kg	161
	Zn	mg/kg	490

Analyses performed by Brookside Labs, New Knoxville, OH.

Table 4. Leachate analysis of LIMB FGD and N-Viro Soil made from Toledo sludge and LIMB FGD as the alkaline reagent.

Parameter	EPTOX (pH 5)	Water Extract	
	N-Viro Soil	N-Viro Soil	LIMB FGD
pH	7.41	10.65	10.63
Total analysis (mg/L)			
Al	0.23	0.08	0.13
Ca	3767	1140	1735
Mg	110	0.03	nd
Fe	2.18	0.03	nd
K	9.99	5.04	2.31
Mn	2.17	nd	nd
Na	6.95	3.91	1.53
P	2.50	1.07	nd
S	544	206	624
Ba	0.33	0.54	0.26
Co	0.03	nd	nd
Ni	0.96	1.22	nd
Sr	3.51	1.77	2.44
V	0.08	nd	nd
As	nd	nd	nd
Cd	nd	nd	nd
Cr	nd	nd	nd
Cu	0.73	1.73	nd
Hg	nd	nd	nd
Pb	nd	nd	nd
Se	nd	nd	nd
Si	12.29	0.46	0.19
Zn	0.66	0.19	nd
B	2.75	0.32	3.66
Be	nd	nd	nd
U	0.02	nd	0.06
Mo	0.16	0.10	0.10
Sb	nd	nb	0.27
F	----	12.0	3.5
Cl	----	28.4	66.9
SO_4	----	27.7	1577

Summary

A new sewage sludge stabilization process, the N-Viro Soil process, has been shown to produce a dry, granular, "soil-like" material that has properties that are ideal for mine spoil reclamation. In addition, recent work has shown that coal scrubber waste, FGD, can be used in the N-Viro Soil process as an alternative alkaline reagent, producing a material that has promise for reuse in the electricity generation industry for coal mine reclamation.

Acknowledgments

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