N-VIRO SOIL: ADVANCED ALKALINE SLUDGE STABILIZATION[1]

by

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Abstract: Technologies for advanced sewage sludge treatment have remained unchanged until the last decade. Since then, large-scale composting has emerged as a viable technology, as has the N-Viro Soil process for Advanced Alkaline Stabilization. Developed by Dr. Jeffrey Burnham and N-Viro Energy Systems, Inc., this technology uses a combination of microbiological stresses to achieve virtually complete pathogen destruction, and has been certified by US EPA as a process to further reduce pathogens (PFRP). The basis for the technology is the use of alkaline admixtures such as cement kiln dust (CKD), an alkaline by-product of the cement industry to achieve alkaline pHs (>12), rapid drying and temperature rise. Other alkaline admixtures that have been successful include lime kiln dust, fly ash, fluidized bed ash and wood ash. The final product is a solid, granular, odor-free material with many of the desirable properties of soil. This, together with its PFRP designation, give N-Viro Soil great flexibility in terms of its beneficial end use.

In this paper I describe the N-Viro process for sludge treatment, identify major physical, chemical and biological properties of N-Viro Soil, and discuss the use of N-Viro Soil for various beneficial end uses.

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

These stresses are produced in the sludge/CKD mixture through the unique properties of the CKD. Typical properties of CKDs are summarized in Tables 1 and 2. Of particular interest are its alkali content (stresses 1, 3 & 4), fine particle size (stress 2), and low moisture content (stress 2). Not apparent from the analysis is the high content of inert material which keeps the concentration of soluble salts from being excessive, but contributes to pathogen kill. As with compost, mesophilic temperatures (52-62^{0}C) and a soil-like environment contribute to the growth of indigenous microorganisms and suppress the regrowth of pathogens or putrifying organisms.

Raw primary activated sludge, or digested sludge with solids content of 18-40% is used. The use of raw primary sludge is preferred to conserve nitrogen in the final product and to reduce NH_3 emissions from the alkali addition. Anaerobically digested sludges can be treated, but NH_3 loss is greatest. Sludge, CKD and other additives are mixed

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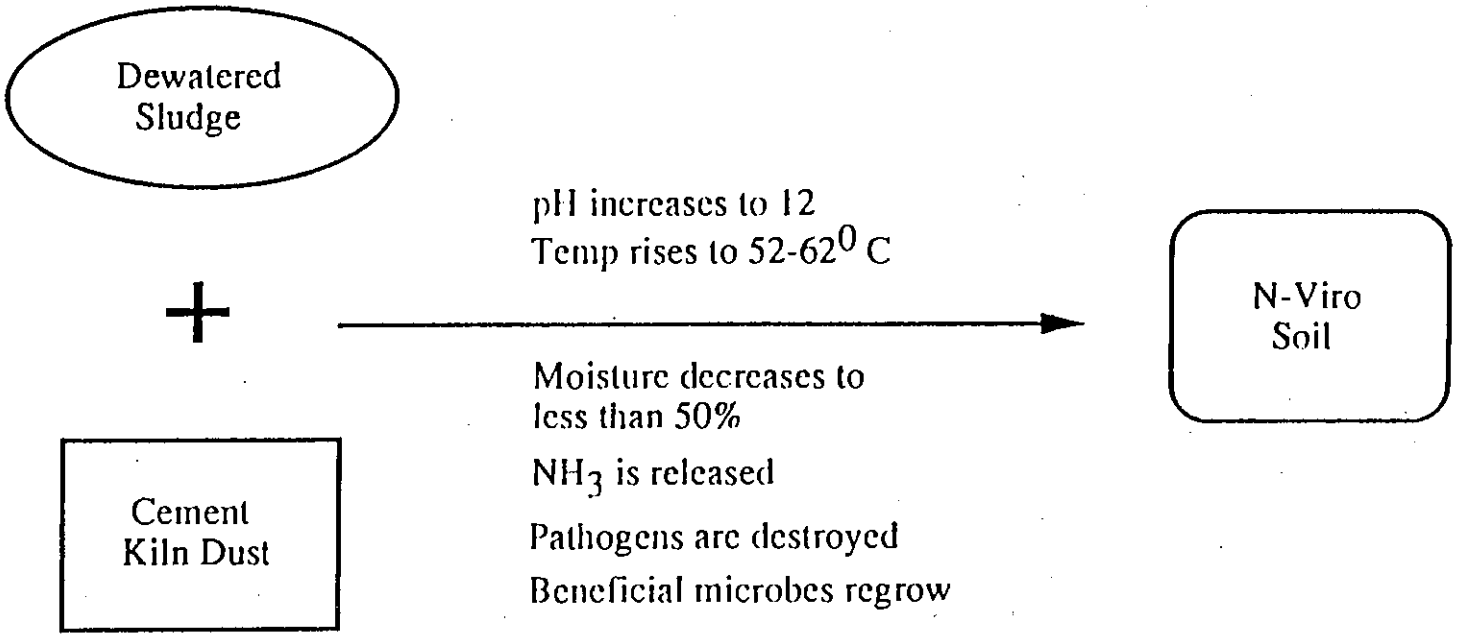


Figure 1. Basic reactions in the N-Viro process.

Table 1. Characteristics of Cement Kiln Dust and the N-Viro Soil Made From It (Logan et al., 1989).

Parameter	CKD	N-Viro Soil*
pH (1:1 water)	13.0	11.1
Elements (% by wt.)		
N	<0.01	1.40
P	0.04	0.39
K	1.61	1.00
Ca	28.5	19.8
Mg	1.22	0.97
Na	0.60	0.20

*CKD was added to sludge at a 35% by weight of dry sludge solids.

Table 2. 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

with a pug mill or screw blender (Figures 2-4). If the CKD contains enough free lime (CaO, $Ca(OH)_2$ or other strong alkali) to give a pH rise to >12 and an exothermic reaction necessary to achieve desired temperatures (52-62°C), no other additive is needed. CaO is added to supplement the free lime content of the CKD if it is not "hot" enough. The ratio of CKD to sludge solids varies primarily with the solids content of the sludge, with a higher ratio being used for sludges with lower solids content (Figure 5). There is a tradeoff here between the cost of sludge dewatering and the residual lime content of the final product. Beneficial use options for the N-Viro product should be considered together with sludge dewatering costs in designing a given system. With proper mixing speeds, the resultant product is a granular, easy-to-handle soil-like material (Webster, 1991) that is further processed by one of two methods: Alternative 1 or Alternative 2.

Alternative 1: The sludge/CKD 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°C.

Alternative 2: The sludge/CKD mixture is heated while the pH exceeds 12.0 using exothermic reactions from the alkali in the CKD and CaO, if required. Temperatures must be 52°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.

Pathogen Kill

The N-Viro process utilizes *pasteurization* rather than *sterilization* to kill pathogens and stabilize the sludge. The distinction is important because in sterilization there is an opportunity for recolonization by pathogenic or putrifying organisms with subsequent health and odor problems. In pasteurization, the mesophilic temperatures and other stresses are great enough to kill the pathogens without destroying the more ubiquitous heterotrophic microorganisms found in the soil. These continue to degrade sludge compounds with the result that N-Viro Soil becomes more stable with aging.

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 5g sludge within 6 hours (Figure 6, Burnham et al., 1990). It should be noted that the N-Viro test for Ascaris kill involves seeding the sludge with viable ova because most sludges are usually low in this parasite.

Odor Control

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 CKD, 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 heterotrophic soil microorganisms. An odor test using a logarithmic scale was used to show that the N-Viro process rapidly reduced sludge odor and maintained odor control for extended periods (Figure 7).

Odor control and sludge stabilization are due, in large part, to the pasteurization process which maintains a high population of indigenous organisms. Figure 8 (Burnham et al., 1990) shows that bacterial numbers in sludge cake were rapidly reduced in the N-Viro Soil but numbers stabilized at about 10^4 per 5 g sludge. Total bacterial numbers in aged N-Viro Soil are similar to those in an agricultural soil (Figure 9, Burnham et al., 1990).

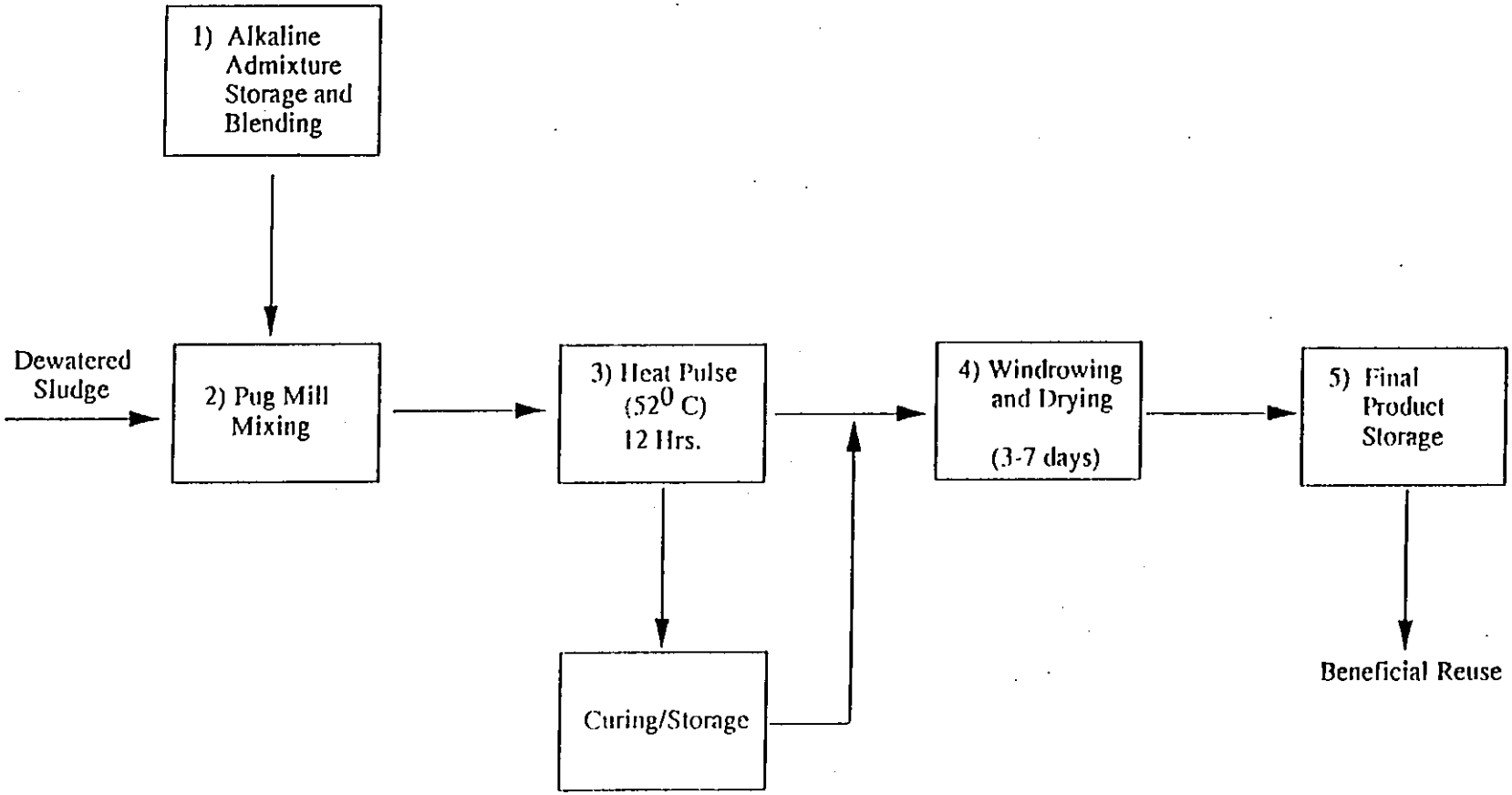
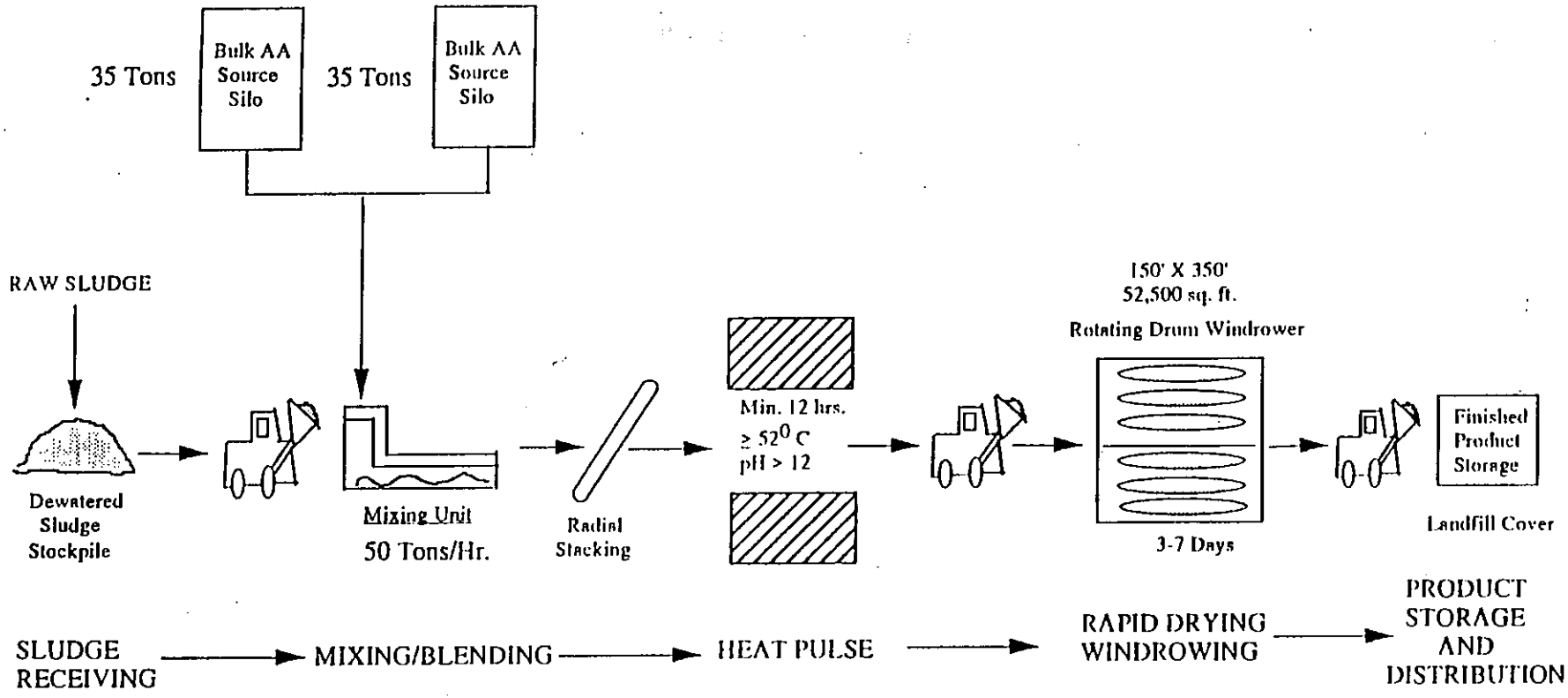


Figure 2.

ADVANCED ALKALINE STABILIZATION WITH SUBSEQUENT ACCELERATED DRYING (AASSAD) PROCESS STEPS TO PRODUCE PFRP GRANULAR PRODUCT

FIGURE 3. PROCESS STEPS IN THE AASSAD PROCESS

UNIT PROCESS OPERATION	DESCRIPTION
1) Alkaline Admixture Storage & Blending	The N-Viro process requires AA dose rates ranging from 25%-50% of the sludge cake wet weight. Approved admixtures are stored in silos and can be blended to produce the end product. Bulk storage silos, suitable for receiving and storing a highly alkaline material, typically receive 24 ton pheumatically discharged loads. Alkaline materials are normally conveyed from the silo to the mixing unit by screw conveyor. At the mixing unit, a metering screw and an optional weighing screw convey a measured amount of each alkaline material into the mixer. The alklaine admixture conveyors are totally enclosed to prevent release of dust.
2) Mixing	Alkaline admixture and dewatered sludge cake are blended in a mixer designed to provide complete and intimate contact between the materials. Design of the mixer is based on the requirement to properly blend the two materials without breaking the structure of the sludge cake and producing a paste-like material. The discharge from the blender should resemble small granular pellets or sand-like grainy particles. The mixing unit is enclosed to prevent release of dust. and to allow exhaust air containing ammonia fumes to be treated.
3) Heat Pulse	The blended material must be "cured" for at least 12 hours while the temperature is monitored and maintained above 52^0 C and below 62^0 C. All the blended material must be placed in Heat Pulse Containers (HPC), storage bins or enclosed piles. Additional storage can also be provided for more than 12 hrs. of curing.
4) Accelerated Drying and Windrowing	The blended material is transported and discharged into long piles forming windrows. The material is aerated and windrowed for 3-7 days. and is complete when the solids content of the material is above 50% TS, while the pH remains above 11. Further windrowing may be desirable to reduce volumes of material to be handled, bringing the solids content to 60-65% TS. Accelerated drying is performed on an asphalt or concrete pad, outdoors or inside a building, using an auger attachment, rotating drum or lift and turn type of accelerated drying equipment.
5) Final Product Storage	The final product storage pad is used to hold material for distribution as required. The product is easily handled and can be stockpiled with stacking conveyors or front end loaders. Because the material meets PFRP requirements, and odors are controlled. it can be stored on-site in accordance with the product distribution and beneficial reuse plan.



MATERIALS	SLUDGE	SLUDGE/AA MIX	HEAT PULSE PRODUCT	FINISHED N-VIRO SOIL
Wet Tons/Day	175	224	224	120
Dry Tons/Day	35	84	84	84
Cu. Yds/Day (est.)	200	240	240	130
Solids %	20%	38%	38%	70%

FIGURE 4.

FLOW DIAGRAM OF N-VIRO PROCESS FOR
EAST BAY MUNICIPAL UTILITY DISTRICT, (OAKLAND, CA)
LOCATED AT THE REDWOOD LANDFILL, (NOVATO, CA)

Figure 5. Relationship between sludge solids content and alkaline admixture (CKD) dose required.

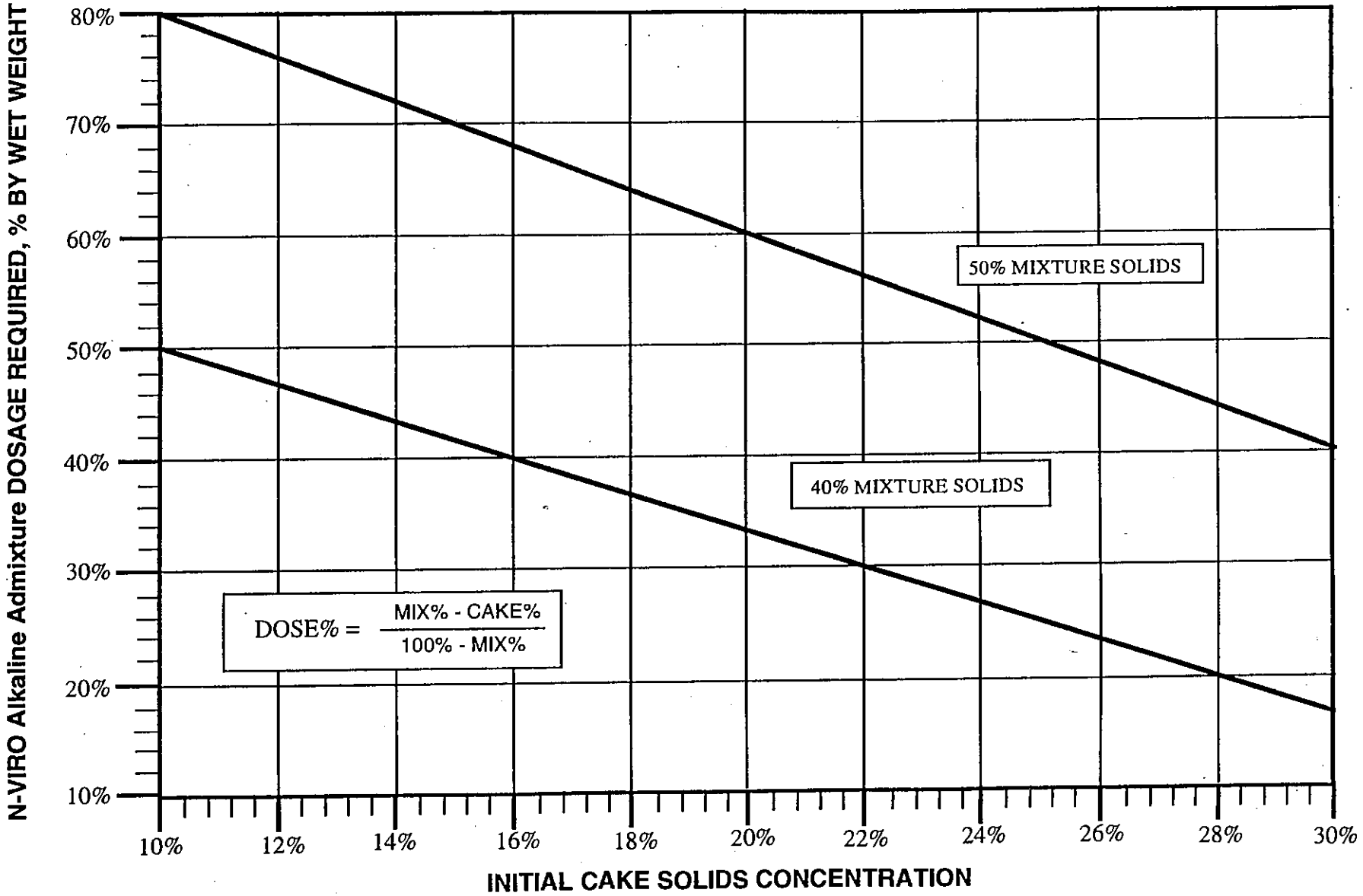


Figure 6. Effect of N-Viro Process on Ascaris Egg Survival.

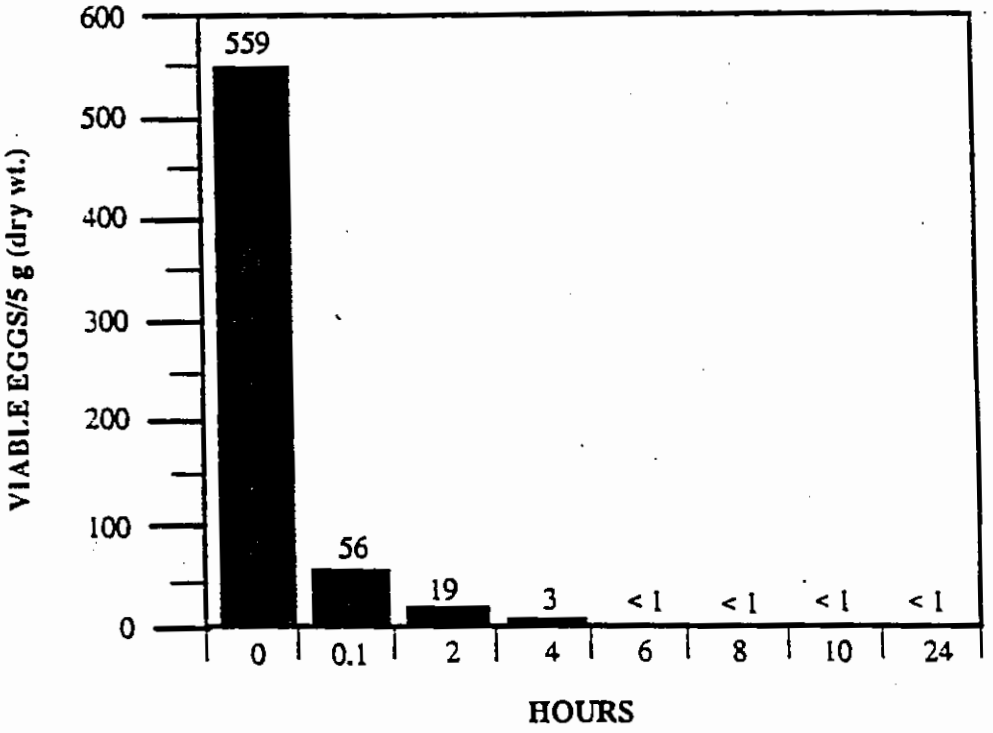


Figure 7. Effect of N-Viro Process on Reduction in Soil Odor

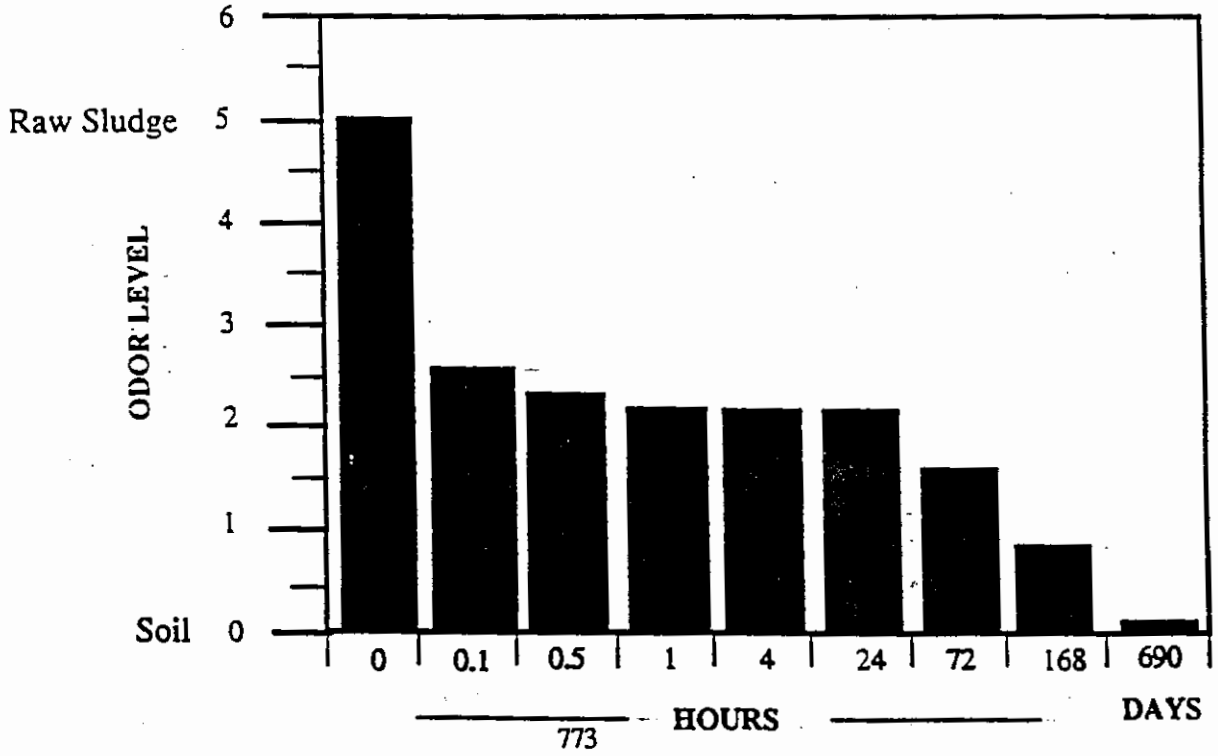


Figure 8. Effect of the N-Viro Process on Bacteria Numbers Compared to Raw Sludge.

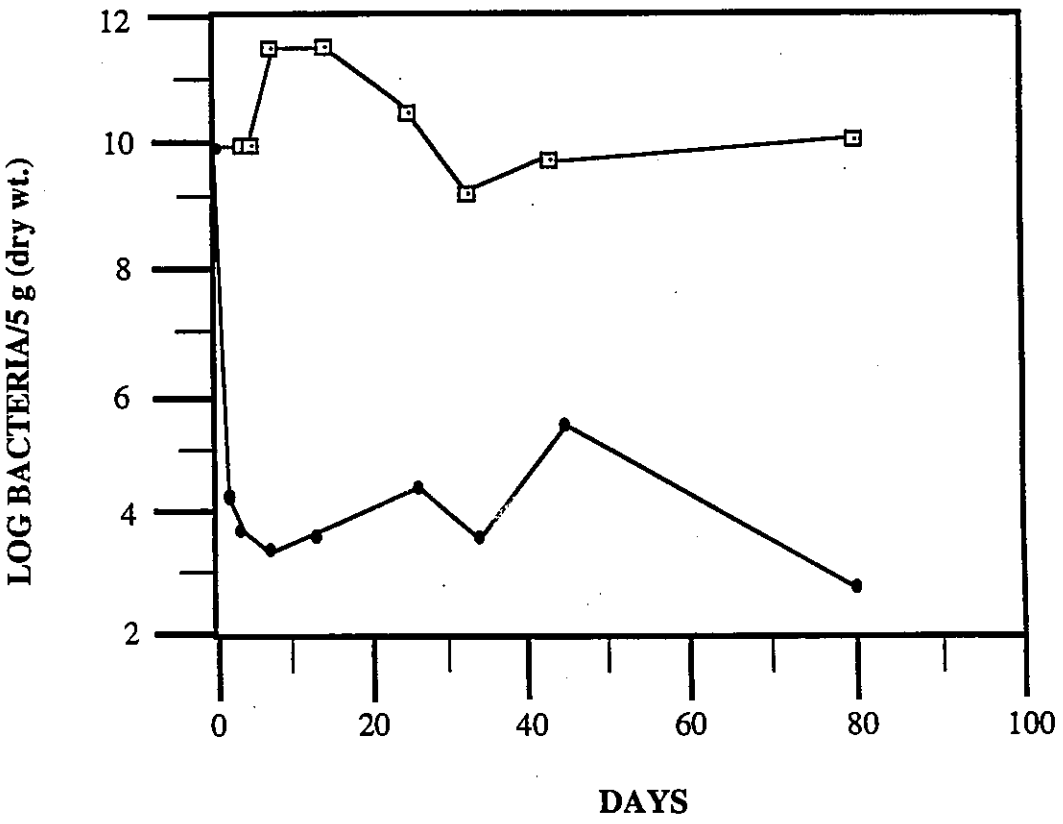
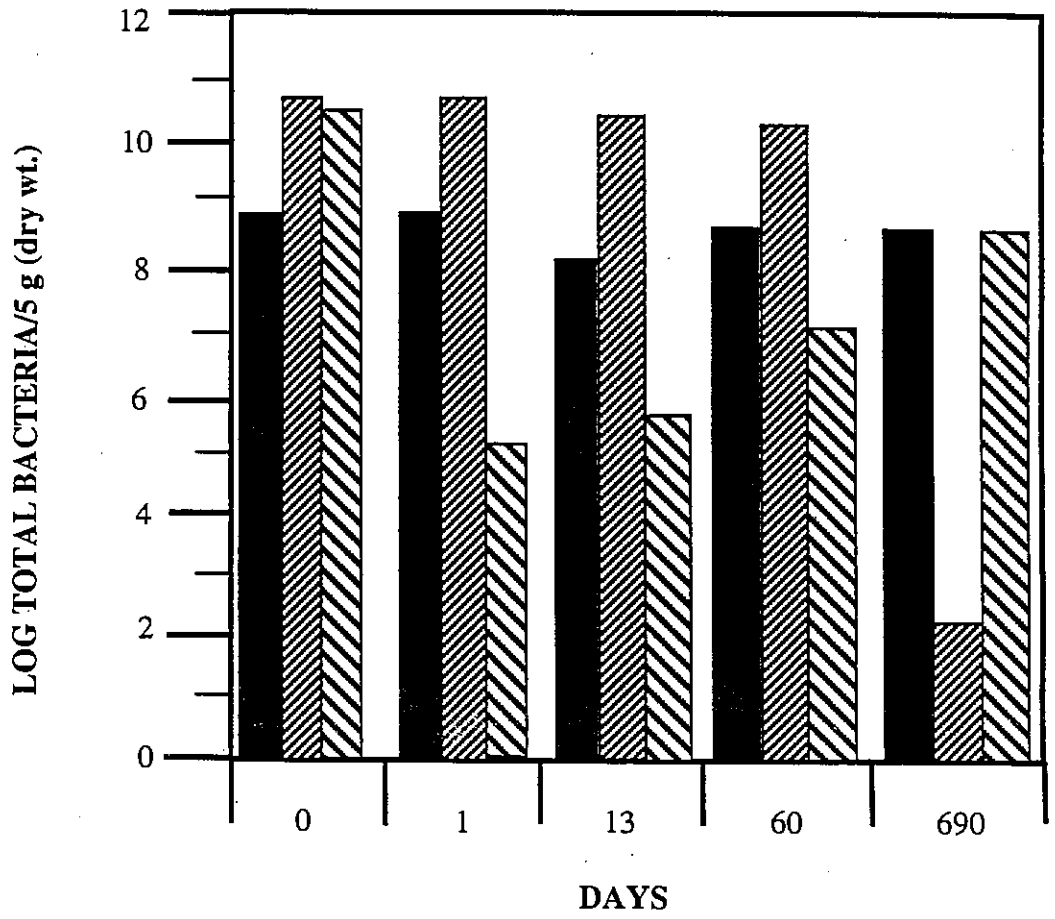


Figure 9. Bacteria Numbers in Field Soil, Anaerobically Digested Sludge & N-Viro Soil with Time.



Product Utilization of N-Viro Soil

Properties of N-Viro Soil

N-Viro Soil is a unique sludge product. Its physical characteristics (Table 2) can be summarized as follows: 1) Dry (50-75% solids); 2) soil-like density (0.7-1.0 g/cm^3); 3) granular (32% by weight > 2mm, mean granule size 0.66 mm). Its chemical characteristics are a combination of those of the CKD and of the sludge (Table 1). N-Viro Soil is an alkaline (pH 11-12) material in which the alkalinity is a combination of strong alkali (primarily $Ca(OH)_2$) and limestone ($CaCO_3$) (see discussion below on soil liming reaction). Most of the base cations (Ca, Mg, K, Na) are contributed by the CKD. These originally exist as oxides, but are hydrated, carbonated, precipitated by sludge constituents such as phosphate, or adsorbed/complexed by sludge organic matter. It is important to note that CKD contains significant amounts of K (1-1.5%), an essential macronutrient, that is usually low in sludge. This gives the N-Viro Soil a more balanced nutrient content than sludge alone. CKD contains very little P, so most of the P in N-Viro Soil is contributed by the sludge. Availability of P in N-Viro Soil is probably initially reduced by the high pH of the product which converts part of the sludge P to Ca phosphates. As pH decreases on addition to soil, P availability will increase. Field studies (Logan et al., 1989) have shown that crops were adequately supplied with P from N-Viro Soil at rates of 4-40 mt/ha.

The dry, biologically and chemically stable nature of N-Viro Soil provide one of its most important attributes: ease of storage. N-Viro Soil can be stored in the field if necessary without producing odors as long as water is not allowed to pond around the base of the pile. As previously discussed, N-Viro Soil improves with age, as pH falls with carbonation, as organic matter is further stabilized by microbial decomposition, and as the solids content increased with drying.

Another important attribute of the material is its granular nature which allows it to be spread with existing equipment such as manure spreaders, sludge cake spreaders and lime and dry fertilizer applicators.

N-Viro Liming Reaction in Soil

As previously discussed, N-Viro Soil contains a combination of strong alkali and $CaCO_3$ (Figure 10), most of it as $CaCO_3$. Strong alkali compounds such as $Ca(OH)_2$ have an equilibrium pH in water of 12 or higher, but because they are strong bases they are rapidly neutralized. Limestone ($CaCO_3$), on the other hand, is relatively insoluble in water and this property gives it its ability to buffer soil pH when added as agricultural limestone. Limestone has an equilibrium pH in water of 8-8.5. In soil with several percent or more of $CaCO_3$, the pH may be in the range of 7.5-8.2. We have hypothesized that when N-Viro Soil is added to soil, the strong base will be rapidly neutralized by acid in the soil (even a calcareous soil has sufficient acid to neutralize strong alkali) (Figure 10). Subsequently, soil pH will be determined by the liming reaction of the $CaCO_3$ in N-Viro Soil. In this respect, the liming reaction should be the same as that of agricultural limestone, and N-Viro Soil can be used as an agricultural lime substitute with application rates based on the lime requirement of the soil, which is determined by soil test, and the $CaCO_3$ equivalent content of the N-Viro Soil (determined by an acid neutralization test). Figure 11 shows that when N-Viro Soil was added to a fine-textured, calcareous soil at rates of 50 and 500 mt/ha in the laboratory, the pH decreased to about 7.5 instantaneously (the first readings were taken within minutes of adding water to the dry soil/N-Viro Soil mixture). At times up to 3000 hours, pHs remained relatively constant, and were consistent in comparison with pure $CaCO_3$ which has a higher acid neutralizing capacity on a mass basis. In field studies on the same calcareous soil, pHs were in the range of 7.5-8 within weeks of N-Viro Soil application (the soonest that soil samples were taken). Goodale et al. (1990) found a similar pH response in their greenhouse study with N-Viro Soil (see below.)

Figure 10. Liming Reactions of CKD and Sludge

CKD: Contains limestone ($CaCO_3$) and alkali (CaO, K_2O)

REACTIONS:

$CaCO_3 = Ca^{2+} + CO_3^{2-}$ pH = 8.5

$CaO + H_2O = Ca(OH)_2$

$Ca(OH)_2 = C_2^{+} + 2OH^{-}$ pH = 12.5

N-VIRO SOIL

Most of the alkalinity is $CaCO_3$ - behaves in soil like limestone

Strong alkali (Ca(OH)2) content is low and is neutralized immediately in soil.

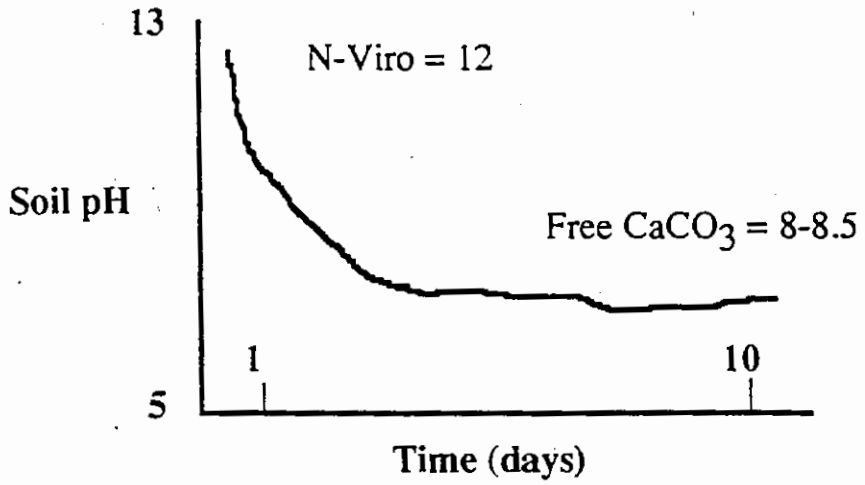
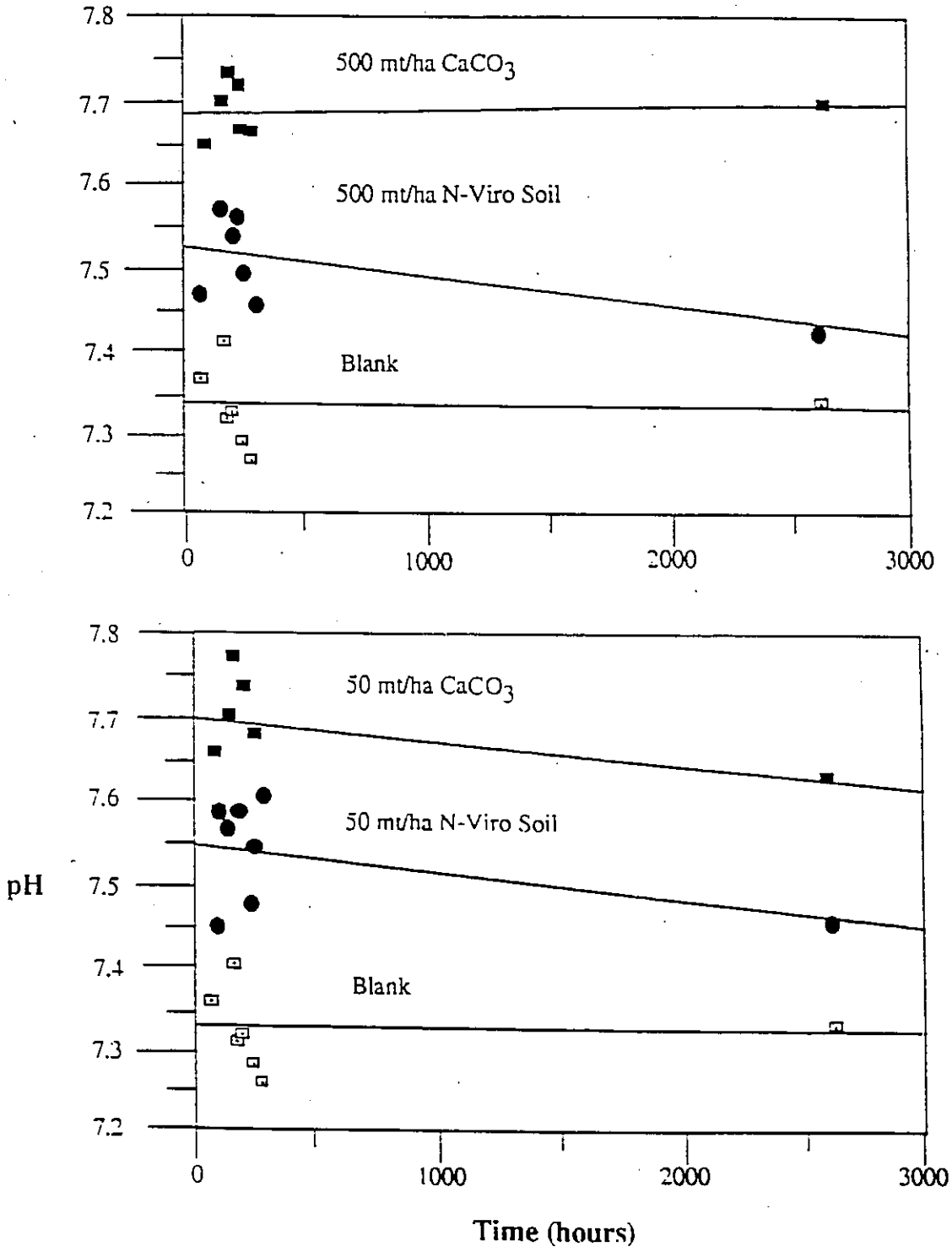


Figure 11. Change in pH of a Calcareous Soil with Addition of N-Viro Soil or Agricultural Limestone.



Nitrogen Availability

All of the N in N-Viro Soil is contributed by the sludge (Table 1), and normally is about 1-1.5% organic N (Table 2) with minor amounts of NH_3 and NO_3. Most of the free NH_3 in the sludge is released as gaseous NH_3 in the initial stages of mixing with the alkaline CKD. The highest N content of N-Viro Soil is achieved with raw primary sludge because more of the N is in the organic form and less as NH_3. A primary consideration in the utilization of any organic waste as a N nutrient source is the rate and extent to which the organic N is converted (mineralized) to NH_3 and NO_3, the forms utilized by plants. Using a standard incubation procedure, Logan et al. (1989) found that 12% of the total Kjeldahl N (TKN) was mineralized in 30 days and 16% in 60 days (Table 3). Mineral N produced in a 60-day incubation is highly correlated with plant uptake in the field in the first crop after application. A N mineralization model (Gilmour and Clark, 1988) overpredicted mineral N production by about 100% (Table 3). It was subsequently shown that part of the NH_3 released by mineralization was strongly adsorbed or otherwise fixed by the N-Viro Soil. After correcting for this fixation, the model results more closely followed those of the incubation study (Table 3). It appears from these results that N-Viro Soil mineralizes N at a rate of about 15-20% of TKN, a value which is similar to that of composted sewage sludge and about 50% of that found for digested sewage sludge.

Trace Metal Immobilization

Cement kiln dust is usually low in trace metals, and N-Viro Energy Systems has a quality control program that screens potential CKDs to be used to make N-Viro Soil. Most of the trace metal in N-Viro Soil comes from the sludge. Therefore, if the N-Viro Soil product is to be used as a fertilizer amendment, it will have to meet metal limits set by the appropriate federal, state and local statutes. CKD will, in most cases, dilute the trace metal content of the sludge. In addition, reactions between the CKD and sludge result in decreased trace metal solubility in the N-Viro Soil. Some of these reactions, such as adsorption to mineral surfaces, precipitation as carbonates and hydroxides, and complexation by soil organic matter, favor cationic trace metal immobilization as pH increases. It appears, however, that trace metals are immobilized in N-Viro Soil even at acid pH. Bennett (1989) studied the mobilization of trace metals from N-Viro Soil by use of a modified EPA Toxicity test (the EP/TOX is a standard acid leaching procedure used to assess hazardous wastes). The samples were pretreated to neutralize the alkalinity in the N-Viro Soil and to give an initial pH of 5. Trace metals extracted from N-Viro Soil were greatly reduced compared to sludge. Using the same test procedure, Bennett extracted trace metals from the field study sites used by Logan et al. (1989), and showed (Figure 12) that less metal was extracted from plots receiving 20 mt/ha N-Viro Soil than from untreated soil. This is in spite of the fact that significant amounts of the six metals were added with the N-Viro Soil.

Crop Response to N-Viro Soil

A number of greenhouse and field studies have been conducted to evaluate the use of N-Viro Soil as a soil amendment for crop production, floriculture and for reclamation. Results from several are summarized here. In a field study, Logan et al. (1989) studied the response of corn and soybean to N-Viro Soil applied at rates of 4 to 40 mt/ha (dry weight) on a calcareous soil. There was no response of corn yield to fertilizer or N-Viro Soil applications because of record drought that year, but there was a trend to higher yields at the 40 mt/ha rate of N-Viro Soil. Field observation suggested that the response might have been physical because the corn on the high rate plots appeared to be less drought stressed. Soybean yields were significantly increased with the higher rates of N-Viro Soil.

In a greenhouse pot study of N-Viro Soil effects on vegetable and flower growth, Goodale et al. (1990) found that N-Viro Soil rates as high as 25% of the media had little effect on pH, and increased soluble salts but below saline levels (Table 5). N-Viro Soil at a rate of 5% of the media increased growth of all

Table 3. Observed and Predicted Nitrogen Mineralization from N-Viro Soil Based on Laboratory Incubation (Logan et al., 1989).

Incubation Time (Days)	Nitrogen mineralized (% of TKN)		
	Observed	Predicted	
		Uncorrected	Corrected for NH_3 fixation
30	12	32	17
60	16	36	20

Table 4. Yields of Corn and Soybeans with N-Viro Soil on a Calcareous Soil from NW Ohio (Logan et al., 1989).

Treatment	Crop Yield (bu/ha)	
	Corn	Soybeans
Check	96.2 ab	30.7 b
Fertilizer	98.5 ab	33.5 ab
N-Viro (4 mt/ha)	96.1 ab	32.9 ab
N-Viro (4 mt/ha)	91.7 b	31.9 ab
N-Viro (9 mt/ha)	89.5 b	32.7 ab
N-Viro (16 mt/ha)	97.4 ab	34.2 a
N-Viro (20 mt/ha)	93.9 ab	34.1 ab
N-Viro (40 mt/ha)	105.6 a	35.1 a

species studied (Table 5), while higher rates were either ineffectual or decreased the growth of all species except oats.

In a greenhouse study of N-Viro Soil use for reclamation of acid mine spoil, Logan and Prezzotto (unpublished) found that N-Viro Soil at rates of 50, 100 and 200 mt/ha gave above-ground biomass yields that were the same as equivalent rates of lime and NPK fertilizer (Figure 13). N-Viro Soil at 200 mt/ha produced more root biomass than the equivalent rate of lime and fertilizer. Field studies in Kentucky have shown that this material is an excellent amendment for reclamation of acid mine spoil.

Conclusions

The N-Viro process for alkaline stabilization of wastewater sludge has been shown to be highly effective in destroying sludge pathogens, reducing sludge odors and in producing a dry, stable product, N-Viro Soil. Characteristics of N-Viro Soil make it an ideal, safe product for use in agriculture as a lime substitute, low analysis fertilizer, and soil amendment. Its physical, chemical and biological properties make it equally suitable for revegetation, landfill cover, and as an ingredient of topsoil.

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Figure 12. Metals Extracted From Field Soil With and Without N-Viro Soil (20 mt/ha) by a Modified EP Toxicity Test (Bennett, 1989).

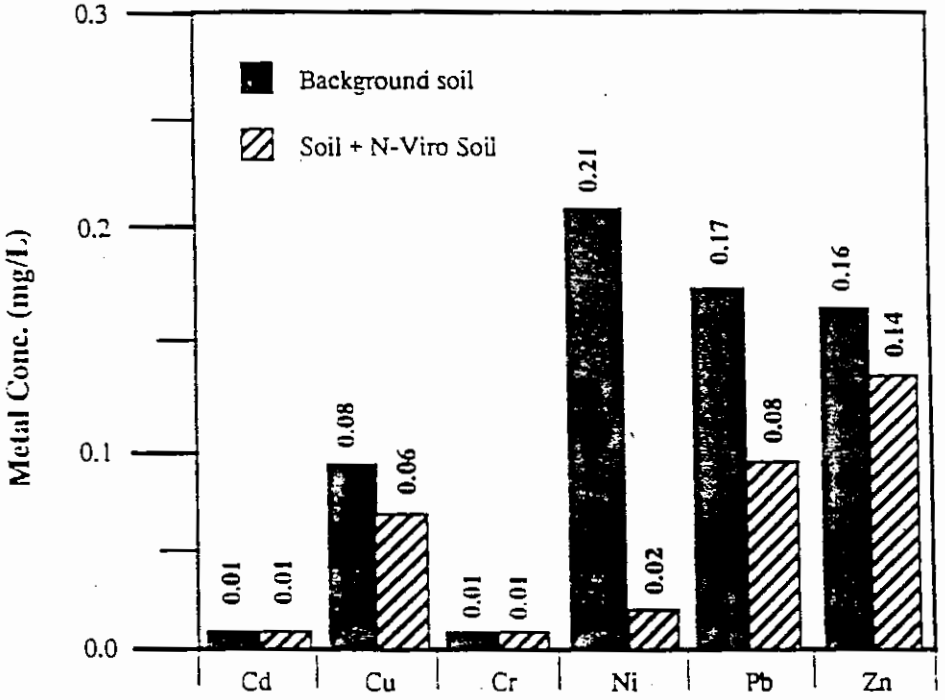

Figure 13. Grass Biomass on Acid Mine Spoil (initial pH 3) with N-Viro Soil and Equivalent Amounts of Lime and Fertilizer.

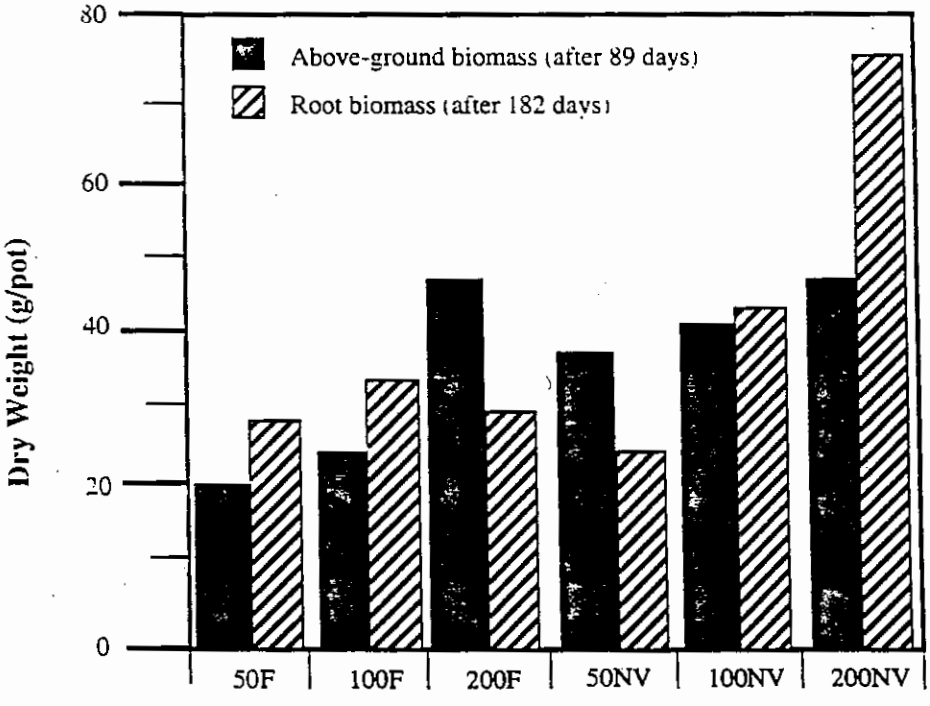

Table 5. Effects of N-Viro Soil on Growth of Vegetables and Flowers in Pot Media (Goodale et al., 1990).

N-Viro (% in media)	Media pH	Salts (mmhos/cm)	Plant Growth (grams dry wt.)				
			Radish Root	Bean Tops	Rye Tops	Oats Tops	Impatients Tops
0	7.5	0.35	0.6	1.0	0.7	0.8	0.5
5	7.3	0.58	2.2	1.7	1.8	1.8	1.3
10	7.4	0.99	2.3	1.9	2.6	5.0	0.4
15	7.6	1.03	2.2	1.2	3.3	4.6	0.8
20	7.9	1.25	2.0	1.1	4.1	6.9	0.4
25	7.4	1.40	1.1	0.5	4.0	6.7	0.4