LONG-TERM EFFECTS OF A SINGLE APPLICATION OF MUNICIPAL SLUDGE ON ABANDONED MINE LAND[1]

BY

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Abstract. In 1977, digested and dewatered municipal sludge was applied and incorporated in spoil material at a rate of 184 Mg/ha on a 0.4 ha experimental plot on an abandoned strip mine site in Pennsylvania. Data were collected for a five-year period (1977-1981) to determine the effects of the sludge application on the quality and growth of the herbaceous vegetation, the chemical properties of the soil, and the chemical quality of groundwater. In 1989, 12 years after sludge application, the site was again resampled to determine the long-term residual effects of the sludge application. Results of the re-evaluation indicated that the single high application of sludge facilitated the rapid development of a vegetative cover which has persisted over the 12 years with no apparent adverse effects on vegetation, soil, or groundwater.

Additional key words: Reclamation, trace metals, sludge utilization, revegetation, groundwater quality.

Introduction

It is estimated that more than 7.7 million dry metric tons of municipal sludge are currently produced each year by the 15,300 public-owned treatment works in the United States. Approximately 25% of this is being land-applied for its fertilizer and organic matter value (Federal Register 1989). One of the most efficient uses for sludge is the reclamation of disturbed lands, such as those abandoned after coal mining which are acidic, droughty, and devoid of organic matter. Sludge has been shown to improve spoil structure, water holding capacity, and bulk density in addition to adding N, P, K, and other plant nutrients (Sopper et al. 1982; Sopper and Seaker 1983).

Approximately 121,000 hectares of land in Pennsylvania, strip mined prior to the federal Surface Mining Control and Reclamation Act of 1977, were abandoned after the coal was removed, leaving vast areas of barren spoil (USDA 1980). These sites have remained barren for years due to the difficulty of establishing and maintaining vegetation on the highly acidic material.

In 1977, a project was initiated in Pennsylvania that introduced the concept of using municipal sludge for revegetation of mined land to the general public in order to gain public acceptance and support. The specific objective of the project was to demonstrate that municipal sludge could be used to reclaim strip mined land and return it to potential agricultural use or to a wildlife habitat in an environmentally acceptable manner, without adverse effects on the quality of the vegetation, soil, or water. Vegetation, soil, and groundwater samples were collected over a five-year period (1977-1981) and results of these studies have been reported by Seaker and Sopper (1984).

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The issue of the long-term effect of applying single, large amounts of sludge in order to revegetate mine land often arises. What happens after all the sludge has been mineralized and all the nutrients and trace metals have been released to the soil and are potentially available for plant uptake and leaching? Will the vegetative cover persist or deteriorate?

One of the sites used in the 1977 project was an abandoned strip mine bank located in Venango County that had been backfilled and recontoured after mining without top soil replacement. Several revegetation attempts were unsuccessful. Dewatered digested sludge was applied in May 1977 to a 0.2-ha plot. In August, 1989, 12 years after sludge application, the site was revisited and samples of vegetation, soils, and groundwater were collected to evaluate the long-term effects. The project was originally designed as a demonstration to the public, rather than an experiment. Subsampling was employed, but statistical analyses could not be performed on the data. Instead, general trends are discussed.

Materials and Methods

Sludge Application

The surface soil was compacted, stony, and extremely acid (pH 3.8). The 0.2 ha plot was scarified with a chisel plow to loosen the surface spoil material and agricultural lime was applied at 12.3 Mg/ha to raise the spoil pH to 7.0. Sludge for the project was obtained from three local wastewater treatment plants. The sludge was applied at 184 Mg/ha with a manure spreader. The average concentrations of nutrients and trace metals and amounts applied in the sludge are given in Table 1. The amounts of nutrients applied were equivalent to applying an 11 (N) -9 (P_2O_5) -0 (K_2O) chemical fertilizer at 22,400 kg/ha.

Table 1. Chemical analysis of dewatered sludge applied and amounts of elements applied at 184 Mg/ha rate (Dwt Basis)

Constituent	Average Concentration	Amount Applied
	mg/kg	kg/ha
Total P	4624	918
Total N	12188	2388
K	93	18
Ca	9970	1834
Mg	2082	383
Zn	811	147
Cu	661	129
Pb	349	55
Ni	69	12
Cd	3.2	0.6
pH	7.9	

The amounts of trace metals applied are given in Table 2 along with the U.S. Environmental Protection Agency (EPA) and Pennsylvania Department of Environmental Resources (PDER) interim guideline recommendations (United States Environmental Protection Agency 1977; Pennsylvania Department of Environmental Resources 1977). It is quite obvious that the amounts of trace metals applied were well below the recommended lifetime limits except for copper, which slightly exceeded the Pennsylvania guidelines.

Immediately after sludge application and incorporation, the site was broadcast seeded with a mixture of two grasses (Kentucky-31 tall fescue, *Festuca arundinacea* Schreb., 22 kg/ha, Pennlate orchardgrass, *Dactylis glomerata* L., 22 kg/ha) and two legumes (Penngift crownvetch, *Coronilla varia* L., 11 kg/ha, and Empire birdsfoot trefoil, *Lotus corniculatus* L., 11 kg/ha). Then the site was mulched with straw and hay at the rate of 3.8 Mg/ha.

Sampling and Analyses

A complete monitoring system was installed on the plot to evaluate the effects of the sludge applications on water quality, vegetation, and soil. Two groundwater wells were drilled (up-gradient and down-gradient) to sample the effects of the sludge application on groundwater quality. After sludge application, groundwater samples were collected bi-weekly for the first two months and monthly thereafter. Samples were analyzed for pH, nitrate-N by ion-selective electrode (Ellis 1976), dissolved Cu, Zn, Cr, Pb, Co, Cd, and Ni by atomic absorption spectrophotometry (EPA Methods of Chemical Analysis 1974).

Minesoil samples were collected at the 0 to 15, and 15 to 30 cm depth, passed through a 2 mm sieve, and analyzed for pH, Kjeldahl-N, Bray-P, exchangeable K, Ca, and Mg by ammonium acetate extraction, and dilute hydrochloric acid extractable Cu, Zn, Cr, Pb, Cd, and Ni (Jackson, 1958). Exchangeable cation and extractable metal concentrations were determined by atomic absorption.

At the end of each growing season vegetation growth responses were determined by measurements of percentage areal cover, and dry matter production. No crops were harvested over the 12-year period. Individual samples of tall fescue, orchardgrass, crownvetch, and birdsfoot trefoil from each plot were collected for foliar analyses. Plant samples were analyzed for Kjeldahl-N; P, K, Ca, Mg, by plasma emission spectrometry (Baker et al. 1964), and Cu, Zn, Cr, Pb, Co, Cd, and Ni by atomic absorption (Jackson 1958), after dry ashing and digestion.

Results and Discussion

Vegetation

The site was completely vegetated by August 1977, three months after sludge application, which has persisted throughout the 12-year period. Average annual dry matter production for the first five years and in 1989 was as follows:

Year	Yield
	Mg/ha
1977	6.0
1978	9.3
1979	11.3
1980	31.2
1981	22.6
1989	15.5
AHY	4.0

Table 2. Trace metal loadings of the sludge application and lifetime loadings recommended by the EPA and PDER.

Constituent	Sludge Application 184 Mg/ha	EPA[1] (CEC 5-15)	PDER
	-------------- kg/ha	----------------	
Cu	129	280	112
Zn	147	560	224
Cr	74	NR[2]	112
Pb	55	800	112
Ni	12	280	22
Cd	0.6	11	3
Hg	0.09	NR[2]	0.6

[1] Average CEC of site ranged from 11.6 to 15.2 meq/100g

[2] No recommendation given by EPA

Dry matter production increased during the first four years, leveling off in 1981. In 1989 it was slightly lower but still well above the average hay yield (AHY) for undisturbed farmland soils in the county. During the first two years the two grass species dominated the site, but by the third growing season, the two legume species predominated and persisted through the fifth year (1981). However, by 1989 the birdsfoot trefoil had almost disappeared and now the dominating vegetative cover consists mostly of crownvetch and orchardgrass.

For brevity, only the foliar analyses for crownvetch and orchardgrass will be discussed. Foliar concentrations of macronutrients are given in Table 3. Nutrients (N and P) were all generally higher in the sludge-grown plants. Potassium and Ca were higher in the sludge-grown orchardgrass than in control plants. Potassium and Ca were only slightly lower in the sludge-grown birdsfoot trefoil plants than in the control plants. Foliar Mg concentrations were similar in both sludge-grown and control plants. Nutrient levels in the sludge-grown plants in 1989 were about the same level as the first year when sludge was applied. There appears to be little depletion of nutrients from the site over the 12-year period. Birdsfoot trefoil data are given in Table 3 because no crownvetch plants were present on the control plot for comparison. Macronutrient concentrations in crownvetch on the sludge-amended plot are given in Table 4. Concentrations were quite similar to those of birdsfoot trefoil.

Foliar concentrations of Zn, Cu, Pb, Ni, and Cd in orchardgrass and crownvetch are shown in Figures 1 to 5. Concentrations of Zn (Fig. 1), and Ni (Fig. 4) tended to be higher in crownvetch than in orchardgrass; whereas, concentrations of Cu (Fig. 2) tended to be higher in orchardgrass. Concentration of Pb (Fig. 3) and Cd (Fig. 5) were variable and showed no distinct trends. In general, trace metal foliar concentrations tended to be highest the first year and then decrease over time. Except for Ni, foliar concentrations of trace metals in the sludge-grown orchardgrass plants were higher than in control plants. The 1989 values for Cu (Fig. 2) and Cd (Fig. 5) were quite similar to those of 1981. Foliar concentrations of Zn, Ni, and Pb showed a slight increase from 1981 to 1989. Although sludge application appeared to increase some trace metal concentrations in the foliage, these increases were minimal and well below the suggested tolerance levels for agronomic crops (Melsted 1973). No phytotoxicity symptoms were observed during the study. The suggested tolerance levels are not phytotoxic levels but suggest foliar concentration levels at which decreases in growth may be expected.

Spoil Chemical Status

Changes in spoil pH over time are shown in Table 5. Spoil pH tended to increase from 1977 to 1979 and declined thereafter. This may explain why some of the foliar trace metal concentrations showed an increase in 1989. The nutrient status of the spoil seemed to show a general increase in concentrations of Kjeldahl-N up to 1981 and up to 1984 for Bray-phosphorus, K and Ca (Table 6). The application of lime and sludge initially resulted in a decrease in the concentration of Mg; however, since 1978 there has been a steady increase. The 1989 values are lower but still quite adequate to support plant growth.

Concentrations of extractable trace metals in the 0 to 15 cm spoil depth are given in Table 7 and for the 15 to 30 cm spoil depth in Table 8. Concentrations of Cu, Zn, Cr, Pb, Cd, and Ni all show a steady increase for the first five years (1977-81). By this time, most of the sludge organic matter was probably mineralized and most of the trace metals released to the surface spoil. Results of spoil analyses in 1984 and 1989 showed a gradual decrease in concentrations of all trace metals. Although the sludge application seemed to increase the concentrations of extractable trace metals in the 0 to 15 cm spoil depth, these higher concentrations are still within the normal ranges for these elements in U. S. soils (Allaway 1968).

It appears that there is some leaching of trace metals through the spoil profile. Concentrations of trace metals in the 15 to 30 cm spoil depth show a general increasing trend from 1977 to 1989.

Groundwater Quality

Results of the analyses of groundwater well samples are given in Table 9. The values for Well

Table 3. Mean foliar concentrations of macronutrient elements in orchardgrass and birdsfoot trefoil collected from the control and sludge-amended plots.

Sludge application	Year	Orchardgrass					Birdsfoot trefoil				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
Mg/ha		----------%----------					----------%----------				
0	1977	1					1				
	1978	0.92	0.18	1.51	0.36	0.23	1.03	0.24	1.93	0.61	0.26
	1979	1.17	0.22	2.41	0.30	0.22	2.59	0.14	1.74	1.82	0.40
	1980	1.11	0.24	1.86	0.32	0.20	2.11	0.17	1.92	1.02	0.23
	1981	1.22	0.18	1.62	0.68	0.22	3.32	0.17	1.89	1.52	0.29
	1989	1.67	0.17	1.82	0.42	0.30	2.31	0.17	1.71	0.92	0.22
184	1977	2.62	0.40	2.84	0.84	0.31	3.64	0.27	1.46	1.99	0.28
	1978	1.26	0.37	2.01	0.49	0.28	1.27	0.36	2.30	0.59	0.25
	1979	1.33	0.51	2.53	0.47	0.23	3.57	0.25	1.56	0.54	0.20
	1980	1.70	0.42	2.65	0.45	0.23	2.93	0.25	1.62	1.27	0.18
	1981	2.57	0.37	2.38	0.53	0.26	4.03	0.26	1.69	1.14	0.23
	1989	2.36	0.37	2.24	0.45	0.22	2.38	0.16	1.01	0.65	0.23

[1]No plants available for sampling

Table 4. Mean foliar concentrations of macronutrient elements in crownvetch on the sludge-amended plot.

Year	Crownvetch				
	N	P	K	Ca	Mg
	----------------------%----------------------				
1977	3.36	0.34	1.64	2.63	0.42
1978	2.35	0.37	3.14	0.96	0.45
1979	3.35	0.22	1.29	1.68	0.25
1980	3.00	0.27	1.89	1.72	0.29
1981	3.78	0.31	1.89	1.25	0.23
1989	2.62	0.21	2.20	0.91	0.26

Table 5. Changes in Spoil pH over the thirteen year period

Depth	Soil pH					
	May 1977[1]	Sept 1977	Nov 1978	Oct 1979	May 1981	Aug 1989
cm						
0-15	3.8	6.2	6.7	7.3	5.8	5.4
15-30	3.8	4.2	4.6	5.1	3.4	5.6

[1]Pre-treatment samples

1 (control) reflect quality of groundwater for the disturbed mine site. Well 2 reflects the effects of the sludge application on water quality. Depth to the water table was 4.9 m in Well 1 and 3.0 in Well 2 in 1989. During the first five years (1977 to 1981) the water table fluctuated between 4.4 to 5.3 m in Well 1 and between 2.5 and 3.4 m in Well 2. Results indicate that the sludge application did not appear to have any significant effect on groundwater concentrations of nitrate-N. Average monthly concentrations of NO_3-N were below 10 mg/l (maximum concentration for potable water) for all months sampled during the five-year period (1977-81). The highest monthly values were 3.0 mg/l for the control well and 2.4 mg/l for Well 2.

Application of lime and sludge and subsequent revegetation appears to have had a positive effect on groundwater pH (Table 9). Groundwater pH increased from 4.6 (1977) to 6.0 by 1981. Results of the 1989 sampling indicated a pH of 6.6. There has also been a gradual increase in pH in the

Table 6. Changes in concentrations of Kjeldahl-nitrogen, Bray-phosphorus and exchangeable cations in the spoil collected at the 0-15 cm depth

Year	Kjeldahl Nitrogen	Bray Phosphorus	K	Ca	Mg
	%	----------------	mg/kg	----------------	
May 1977[1]	0.04	2	12	541	452
Sept 1977	0.05	11	19	1222	32
1978	0.09	9	23	2600	40
1979	0.16	38	46	3873	53
1981	0.34	79	45	1298	99
1984	---	91	74	1440	108
1989	0.12	83	30	733	84

[1] Pre-sludge samples

Table 7. Changes in concentrations of extractable trace metals from spoil collected at the 0-15 cm depth following sludge application.

Sampling Date	Cu	Zn	Cr[2]	Pb	Cd	Ni
	----------------		mg/kg		----------------	
May 1977[1]	2.5	2.9	0.2	0.5	0.02	1.1
Sept 1977	10.8	7.7	0.4	3.5	0.04	0.9
1978	8.8	7.7	0.2	2.3	0.02	1.2
1979	58.7	56.9	1.7	13.0	0.27	1.5
1981	87.3	74.6	3.5	22.7	0.95	2.8
1984	57.6	59.6	---	14.8	0.56	2.8
1989	51.9	37.8	---	13.5	0.42	2.0
Normal Range for U.S. Soils	2-100	10-300	5-3000	2-200	0.01 7.00	5-500

[1] May 1977 values represent pretreatment conditions
[2] Values for Cr are total concentrations.

control well from pH 4.4 to pH 5.8. Since 1980, attempts have been made to reclaim the control area by conventional methods using lime and fertilizer. The amounts of lime and fertilizer applied and frequency of application are not known as the coal company is no longer in business. However, these applications and vegetation growth probably contributed to the increase in groundwater pH in the control well.

There appears to be no significant increase in any of the trace metal concentrations over the initial five-year period (1977-1981) in the groundwater samples from Well 2 compared to the control well (Table 9). From 1977 to 1981 most of the monthly concentrations were within the U.S. Environmental Protection Agency drinking water standards. The only exception was Pb which exceeded the limit of 0.05 mg/l for both the control well and Well 2, probably resulting from solubilization upon weathering after mining. The highest monthly Pb values were 0.28 mg/l in the control well and 0.33 mg/l in Well 2 in 1978, and the mean annual Pb concentrations were 0.19 and 0.20 mg/l for control well and Well 2, respectively. By 1981, however, the mean annual Pb concentrations had decreased to 0.04 and 0.05 mg/l for the two wells. Results of analyses of the groundwater samples collected in 1989 had extremely low concentrations of all trace metals in both wells in comparison to values for the initial five years (1977-81).

Conclusions

Re-evaluation of an abandoned strip mine spoil bank 12 years after being amended with 184 Mg/ha of

Table 8. Changes in concentrations of extractable trace metals from spoil collected at the 15-30 cm depth following sludge application.

Sampling Date	Cu	Zn	Cr	Pb	Cd	Ni
	mg/kg					
May 1977[1]	3.0	2.4	0.10	0.6	0.020	1.0
Sept 1977	4.0	2.0	0.10	1.3	0.010	0.4
1978	2.5	1.7	<0.01	1.3	0.007	0.7
1979	9.2	8.7	0.28	2.4	0.026	0.2
1981	2.4	2.8	0.05	0.5	0.014	0.4
1989	13.8	10.2	0.43	3.8	0.122	1.9

[1]May 1977 values represent pretreatment conditions
[2]Values for Cr are total concentrations

Table 9. Mean annual concentrations of nitrate - N and trace metals in groundwater

Site	Year[1]	pH	NO_3-N	Cu	Zn	Cr	Pb	Cd	Ni
			mg/l						
Well 1	1977	4.4	1.4	0.22	4.13	0.02	0.14	0.006	3.67
(control)	1978	4.3	<0.5	0.23	2.02	0.01	0.19	0.002	0.98
	1979	4.6	<0.5	0.17	1.48	0.03	0.13	0.001	0.50
	1980	5.5	0.6	0.05	0.89	0.05	0.09	0.001	0.50
	1981	5.7	0.7	0.06	0.83	0.03	0.04	0.003	0.31
	1989[2]	5.8	0.02	0.01	0.09	<0.001	0.01	0.001	0.06
Well 2	1977	4.6	1.1	0.10	3.39	0.03	0.09	0.001	2.67
(sludge)	1978	4.5	<0.5	0.14	3.29	0.01	0.20	0.002	1.26
	1979	4.4	<0.5	0.18	1.49	0.03	0.13	0.001	0.97
	1980	5.7	0.6	0.05	1.05	0.04	0.11	0.001	0.76
	1981	6.0	0.6	0.05	0.57	0.02	0.05	0.001	0.31
	1989[2]	6.6	0.06	0.01	0.07	<0.001	0.01	0.001	0.04
EPA drinking water standard			10	1	5	0.05	0.05	0.010	---

[1]Values are annual means of monthly samples.

[2]Average of three samples collected in August 1989.

municipal sludge indicates that a single large application of sludge can be used successfully to revegetate mine lands with no apparent adverse effects on vegetation, spoil, or groundwater quality.

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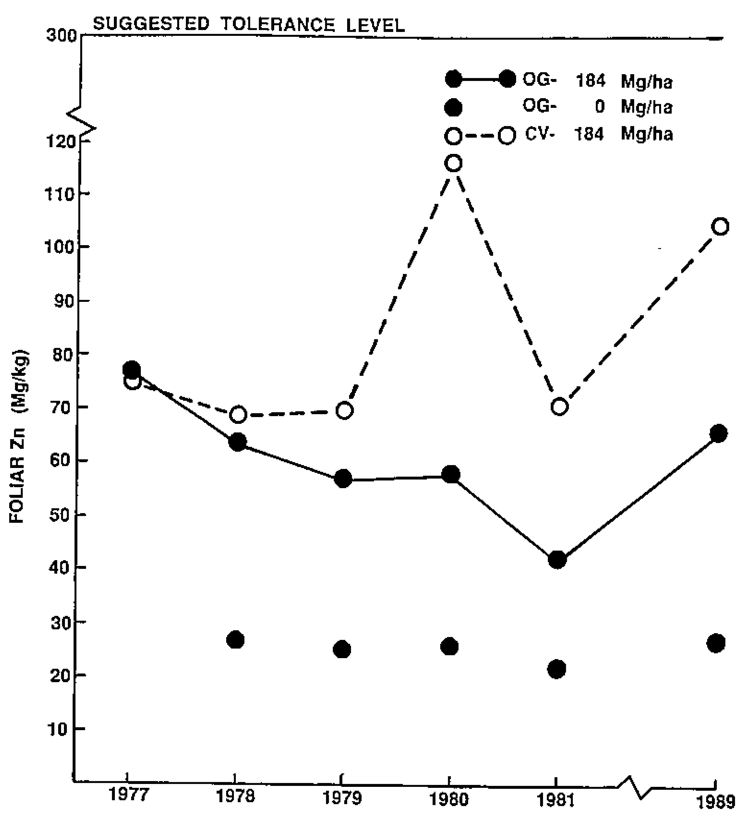

Figure 1. Mean foliar concentration of Zn in orchardgrass and crownvetch collected from the control and sludge-amended plots.

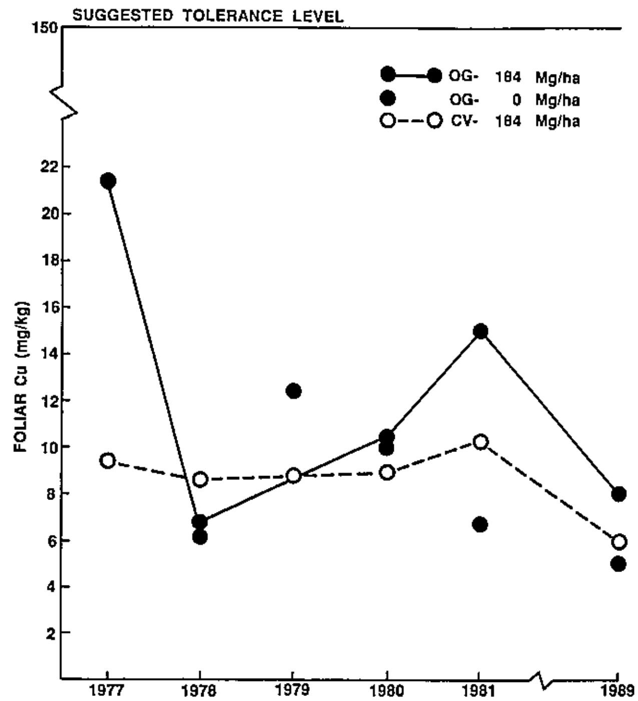

Figure 2. Mean foliar concentration of Cu in orchardgrass and crownvetch collected from the control and sludge-amended plots.

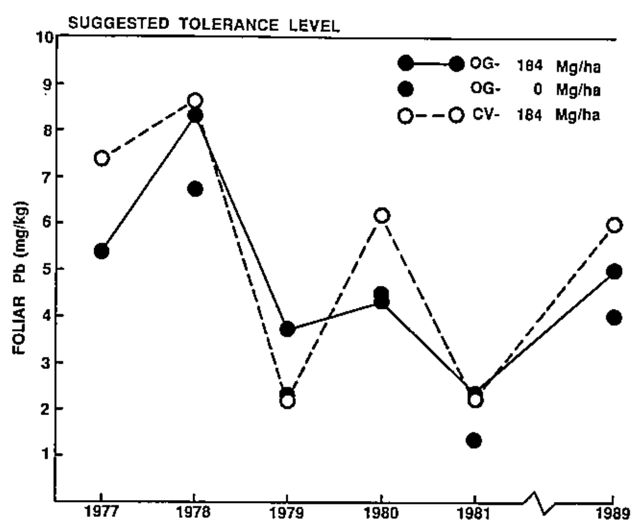

Figure 3. Mean foliar concentration of Pb in orchardgrass and crownvetch collected from the control and sludge-amended plots.

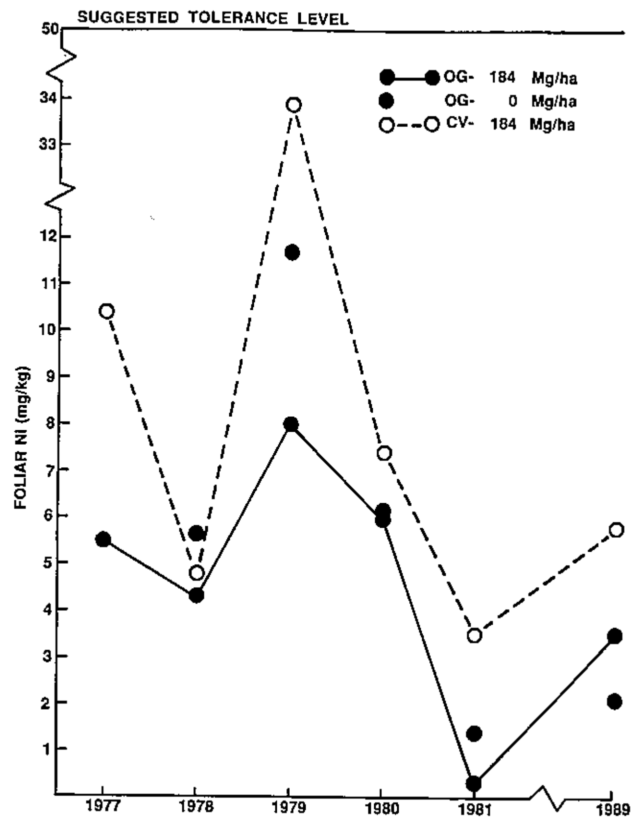

Figure 4. Mean foliar concentration of Ni in orchardgrass and crownvetch collected from the control and sludge-amended plots.

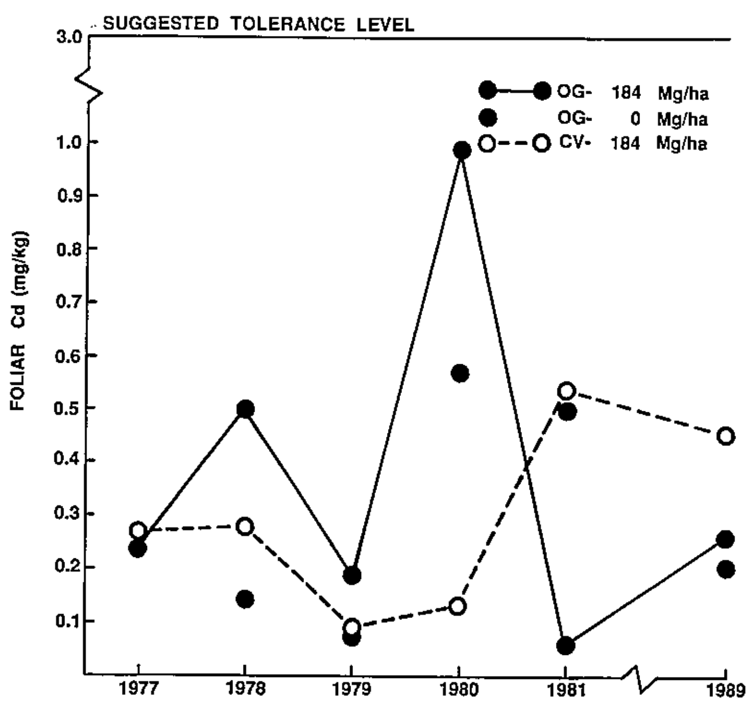

Figure 5. Mean foliar concentration of Cd in orchardgrass and crownvetch collected from the control and sludge-amended plots.