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Project Summary

Effects of Using Sewage Sludge on Agricultural and Disturbed Lands

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A series of studies was conducted to determine the effects of using sewage sludge on agricultural and disturbed lands. The studies included examinations of soils, drainage water, runoff, and crops from both field and lysimeter plots treated with digested sewage sludge from Chicago. In addition, several special studies were conducted to compare metal uptake in various corn inbred hybrids. Further studies were conducted to assess the effects of certain sludge constituents on animals that consume plants grown on sludge-amended soils.

Forty-four lysimeters were constructed (3.1 x 15.25 m) with three significantly different soils types — Elliott silt loam (10 lysimeters), Plainfield sand (10 lysimeters), and Blount silt loam (24 lysimeters). Field plots were all Blount silt loam and measured 6.1 x 12.2 m. Digested municipal sewage sludge from Chicago was applied to both types of plots annually, first by overhead sprinklers and later by furrow irrigation. Applications were made for 8 years on the lysimeter plots and 10 years on the field plots. Drainage and runoff samples were analyzed for fecal coliforms. NH_4-N, P, K, Na, Zn, Cu, Ni, Cd, Cr, Pb, Fe, Mn, Se, As, Se, Hg, total solids, and organic carbon.

Corn and soybean crops grown on the plots were analyzed for yield, metals, N, and P. Sludge samples were also taken and analyzed at every application.

Runoff and drainage waters from sludge-treated lysimeter plots often had slightly higher concentrations of NH_4-N, NO_3-N, P, K, Na, Zn, Cu, Ni, Cd, Cr, total solids, organic carbon, and electrical conductivities than did similar samples from the control plots. Concentrations of NO_3 were increased markedly in drainage water. Soil concentrations of several chemical elements also increased, but the P-toxicity in soybeans was the only phytotoxic condition produced by excessive sludge loading rates applied each year. Metal concentrations in corn and soybean tissues, and especially in corn grain, decreased rapidly after sludge applications were terminated. Soil type had no significant effects on metal uptake by corn.

Testing of inbred corn lines and their progeny suggested that metal uptake could be controlled through plant breeding. These tests also showed that major portions of Cd and other inorganic elements were contained in the grain fractions used as animal feed.

Applying sludge each year for 10 years on continuous corn plots improved the physical properties of the soil and never adversely affected seed germination. Sludge application to soil appeared to have no deleterious effects on microbial populations or enzyme activity in the soil.

No adverse health or performance effects were observed in the pheasants and swine that were fed crops from sludge-amended soils.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Digested sewage sludge is an effective source of both nitrogen and phosphorus for the fertilization of growing crops. When sludge is applied by ridge and furrow irrigation, crop yields are equal to or greater than those obtained with inorganic fertilizers applied at rates adequate for maximum yields. But concern exists over the possible uptake of metals by food crops and their subsequent effects on human health. For example, if cadmium levels in food are sufficiently elevated, it is conceivable that this metal will accumulate in kidneys and eventually create chronic illness.

This study was conducted to determine the effects of using sewage sludge on agricultural and disturbed lands. The project included examinations of soils, drainage water, runoff, and crops from both field and lysimeter plots treated with digested sewage sludge from Chicago. Special studies were also conducted to assess the effects of certain sludge constituents on animals that consume plants grown on sludge-amended soils.

Municipal sewage sludge was applied annually to lysimeter and field plots at variable rates. The 3.1- by 15.25-m lysimeter plots and the 6.1- by 12.2-m field plots represented three soil types and received sludge applications for 8 and 10 years, respectively. The maximum application rate was approximately equal to the amount of sludge needed to supply ten times the nitrogen required for an optimum corn yield. The other rates were equal to one-half and one-fourth of the maximum rate. Corn and soybeans were grown on both lysimeter and field plots.

Digested sewage sludge from Chicago was applied to all plots, first by overhead sprinklers, and later by furrow irrigation. Water samples were analyzed for fecal coliforms, NH_4-N, P, K, Na, Zn, Cu, Ni, Cd, Cr, Pb, Fe, Mn, Se, As, Se, Hg, total solids, and organic C. Soil samples were collected from 15-cm deep increments annually after plowing and before sludge addition. They were analyzed for total and available metals and nutrients. Soil pH and organic C content were also determined. Sludge samples were taken and analyzed each time an application to soil was made. Corn leaves, grain, and stover were sampled and analyzed for metals, N, and P.

Long-term field plot studies involved variable rates of liquid digested sludges applied in the same manner. as on the lysimeter plots. The soil was Blount silt loam and the crops were corn, soybeans, and wheat. Plants were analyzed for yield and composition, and soils were analyzed annually, as in lysimeter studies.

A special study was conducted to compare the heavy metal and P uptake by corn inbred lines and hybrid crosses from selected inbred lines.

To assess the effects of some of the chemical elements in sludge on the health, performance, and composition of animals that consume the plants grown on sludge-amended soils, crops were fed to pheasants and swine.

Lysimeter Studies

Procedures

Beginning in 1969, sludge from high-rate anaerobic digesters at the Calumet and Stickney wastewater treatment plants near Chicago was applied by irrigation to 44 lysimeter plots measuring 3.1 by 15.25 m. The lysimeter installation was located on a small watershed at the Northeast Agronomy Research Center near Elwood, Illinois.

The lysimeters contained three significantly different soil types. Elliott silt loam was simulated in 10 lysimeters by removing the surface 31 cm of Blount silt loam and replacing it with the surface of Elliott. Plainfield sand was simulated in 10 lysimeters by excavating the Blount silt loam to a depth of 1.52 m and replacing it with sand from a Plainfield soil. Blount silt loam occupied the remaining 24 lysimeters.

Tile drains were installed through the center of each lysimeter plot, and a fiberglass trough was installed at the downslope end of each plot to collect runoff. Both drainage water and runoff were conveyed separately through PVC pipes from the plots by gravity to the basement of an instrument house. Tipping bucket equipment was provided to measure rates and total volume of flows from each of the PVC pipes. Automated sampling equipment was provided for each of the PVC pipes, and for the most part, a 400 ml sample was collected from the second tip of a tipping bucket and again on each sequential 42nd tip of a bucket thereafter for the duration of a flow event.

Sprinkler irrigation was used to apply sludge during the first two years, after which a furrow system of irrigation was used. Sludge was applied at rates equal to depths of 6.4, 12.7, and 25.4 mm. Control plots were irrigated with 25.4 mm of well water on the same day sludge applications were made. All plots were fertilized with KCl to supply 134 kg K/ha before the preparation of seedbeds. Control plots (no liquid sludge) received fertilizer applications of 268 kg N/ha and 134 kg P/ha as NH_4NO_3 and superphosphates. Fertilizer, liquid sludge, and water applications were terminated on all Blount silt loam plots in the north series at the end of the 1973 growing season. Applications of sludge at less than maximum rates were also discontinued on Elliott silt loam and Plainfield loamy sand plots in the north series. But sludge applications were continued on all plots representing these two soil types in the south series until the end of the 1976 growing season. After 1976, sludge was applied only on Blount silt loam plots in the south series.

Amounts of sludge solids and other constituents applied annually to maximum-treated plots are listed in Table 1. Appropriately lesser amounts from a particular tank of sludge were applied to plots treated with one-fourth and one-half the maximum. Amounts of sludge-borne constituents varied from one year to the next because of differences in sludge solids content and weather conditions that controlled the number of applications.

Concentrations of several sludge constituents were monitored in drainage and runoff water from the time the study was initiated. Beginning in 1976, water samples were analyzed for Se, As, Sb, and Hg, even though concentrations of these elements in sludges were relatively low.

Results

Changes in Water Quality

The geometric means of data from sludge-treated plots were compared with those from control plots to determine possible significant differences in water quality resulting from sludge treatment.

Concentrations of Zn, Cd, and Cu in runoff and drainage water were either unaffected by sludge applications or were increased regardless of soil type. But the significant increases in concentrations of these three metals were so low that differences resulting from treatment probably could not have been detected in the absence of the extensive water sampling program that was conducted during this study. Not enough data have been collected to assess adequately the effects of sludge applications on concentrations of Ni, Cr, Pb, Se, As, Sb, and Hg. The data that have been obtained indicated that only Ni and Cr concentrations in effluent waters from sludge-treated sites may be increased slightly. Annual sludge applications over an 8-year period did not appear to have

Table 1. *Amounts (Dry Wt) of Sludge Constituents Applied Annually to Maximum-Treated Plots of Blount Silt Loam, Elliott Silt Loam, and Plainfield Loamy Sand Lysimeter Plots**

Series and year	*Metric tons of solids/ha*	*kg/ha*													
		Total N	*P*	*K*	*Na*	*Ca*	*Mg*	*Fe*	*Mn*	*Zn*	*Cd*	*Cu*	*Ni*	*Cr*	*Pb*
North series:															
1969	*16.4*	*1134*	*819*			*448*	*243*	*860*	*5*	*158*	*7.9*	*36*	*10.7*	*102*	*23*
1970	*52.8*	*2902*	*2067*			*1361*	*821*	*2734*	*17*	*427*	*22.6*	*101*	*22.1*	*266*	*100*
1971	*57.8*	*3532*	*1984*	*535*	*246*	*2062*	*546*	*2526*	*17*	*265*	*13.2*	*69*	*15.6*	*161*	*71*
1972	*44.4*	*2292*	*1174*	*252*	*204*	*2248*	*545*	*1825*	*21*	*192*	*7.8*	*33*	*4.3*	*54*	*46*
1973	*61.1*	*3286*	*2000*	*359*	*414*	*2770*	*653*	*2067*	*32*	*248*	*6.8*	*41*	*5.2*	*87*	*55*
1974	*69.8*	*4933*	*2717*	*361*	*284*	*2055*	*722*	*3190*	*30*	*359*	*21.8*	*117*	*24.2*	*210*	*65*
1975	*54.0*	*3367*	*1681*	*343*	*207*	*1641*	*677*	*2607*	*26*	*245*	*13.4*	*85*	*21.3*	*170*	*60*
1976	*72.0*	*3989*	*2343*	*403*	*269*	*1992*	*858*	*3301*	*40*	*273*	*19.2*	*127*	*32.1*	*219*	*66*
South series:															
1969	*19.3*	*813*	*805*			*399*	*190*	*455*	*4*	*122*	*5.2*	*27*	*7.7*	*79*	*14*
1970	*36.2*	*2329*	*1187*			*989*	*570*	*1723*	*10*	*312*	*22.2*	*69*	*14.5*	*174*	*100*
1971	*104.7*	*3636*	*3010*	*963*	*395*	*3287*	*876*	*3967*	*25*	*464*	*24.0*	*114*	*28.2*	*298*	*124*
1972	*32.2*	*1650*	*943*	*168*	*186*	*1342*	*414*	*1239*	*14*	*135*	*5.8*	*22*	*3.1*	*40*	*30*
1973	*58.8*	*3202*	*1796*	*370*	*379*	*2831*	*653*	*2041*	*31*	*224*	*6.7*	*38*	*7.6*	*76*	*52*
1974	*70.7*	*4803*	*2663*	*357*	*291*	*1868*	*725*	*3339*	*37*	*350*	*21.7*	*114*	*22.6*	*205*	*75*
1975	*52.4*	*3367*	*1681*	*343*	*207*	*1641*	*677*	*2607*	*26*	*245*	*13.4*	*85*	*21.3*	*170*	*60*
1976	*71.3*	*4604*	*2412*	*396*	*248*	*1987*	*870*	*3301*	*45*	*273*	*19.1*	*115*	*30.9*	*226*	*66*

** After the 1973 growing season, sludge applications were terminated on all plots in the north series except for maximum-treated Elliott silt loam and Plainfield loamy sand plots.*

affected concentrations of Pb, Se, As, Sb, and Hg in runoff or drainage water samples collected in 1976 and 1977.

During the last 6 years of the study, no evidence was found that any measured water quality parameter was deteriorating with increased years of annual sludge applications. Also noteworthy (especially with regard to P and heavy metals) is that sludge-amended Plainfield loamy sands yielded about the same concentrations of various elements in their drainage waters as did the sludge-treated Blount and Elliott silt loams.

Surface runoff and drainage water samples from the lysimeter plots were tested for fecal coliforms by the membrane filter method within 36 hr of collection. Concentrations in drainage waters from the three soils types varied widely between seasons. Differences between fecal coliform levels of drainage water from the silt loam soils and Plainfield loamy sand plots are evident in all seasons. The Plainfield loamy sand plots consistently yielded lower concentrations than the finer Blount and Elliott soils. In general, comparisons of untreated and maximum-sludge-treated plots show only a slight increase in coliform counts in the latter.

Soils

Compared with normal soils, those treated with digested sewage sludge contained relatively high levels of Zn, Cd, Cu, Ni, Cr, and Pb. Except for Ni, levels of all of these metals were significantly higher in the surface of soils given maximum sludge treatments. Because of large variations in soil sample contents, Ni concentrations in maximum-sludge-treated soil surfaces were not always higher than those in control plots. Except for Ni, total concentrations of all metals remained unchanged in the soil below the surface plow layer regardless of sludge application rates and soil type. Surface soil pH of maximum-sludge-treated Blount silt loam plots was significantly lower than that of control plots during the last year in the north series and during the last 2 years for those in the south series.

Grain Yields

Before 1974, grain yields on north Blount plots were not affected by the rate of annual sludge applications. But yields increased during the second, third, and fourth years after termination of sludge treatment. Blount silt loam plots in the south series that received one-fourth and one-half the maximum sludge treatments produced less corn grain in 1971 and 1974 than did the irrigated control plots. On the other hand, yields from Blount silt loam maximum-sludge-treated plots were not significantly different from those produced on control plots--except in 1975, in the south series. For this one year, grain yields were lower on maximum-sludge-treated plots ($P<0.05$) than on irrigated control plots. But stover yields from the same maximum-sludge-treated plots were the highest ever produced during the study, regardless of treatment.

Metal Uptake in Plants

Zinc concentrations were increased in all plant tissues by annual sludge applications. Where sludge applications were terminated after 1973 (Blount silt loam in the north series), Zn concentrations in grain and stover from treated and control plots were not significantly different in 1976 and 1977. Zn concentrations in leaves from those plots that had previously received maximum sludge treatments were significantly higher than those in leaves from control plots during 1977, the last year of the study; but levels were less than half those from the last crop year affected by annual sludge applications (1974).

Effects of sludge applications on Cd contents were similar to those on Zn concentrations. After sludge applications were terminated (Blount silt loam, north series, 1973), Cd concentrations in grain from sludge-treated plots continued to be significantly higher than in samples from control plots. But in most years after sludge applications were terminated, leaf and stover samples had Cd concentrations that were two to six times less than in years when applications were made annually.

Field Plot Studies

Procedures

Four replications of 6.1-by 12.2-m plots with four sludge treatments randomized within blocks were established in 1968 on Blount silt loam soil (Aeric ochraqualf, fine, illitic, mesic) occupying part of the cultivated area on the Northeast Agronomy Research Center near Joliet, Illinois. Digested sludge was first applied by furrow irrigation in 1968 and annually thereafter during the growing season. An additional application was sometimes made during the fall after the grain harvest. All plots were annually fertilized with a broadcast application of KCl to supply 134 kg K/ha. Control plots (no liquid sludge) were further treated with annual broadcast fertilizer applications supplying 268 kg N/ha and 134 kg P/ha. As often as weather conditions permitted, liquid digested sludge was transported by truck trailer tanks from the Metropolitan Sanitary District of Greater Chicago Southwest or the Calumet wastewater treatment plants and applied at liquid depths of 25.4 mm (maximum), 12.7 mm (one-half maximum), and 6.4 mm (one-fourth maximum) to each of the appropriate plots on the same day.

Immediately after ridges and furrow were established, corn (*Zea mays* L.) was planted at rates calculated to give a plant population of 60,000 plants/ha on top of ridges spaced 76 cm apart. In general, sludge was applied for the first time each year when corn plants had reached a height of about 15 cm.

Samples of sludge, soil, and plant tissues were collected and analyzed by the same methods and procedures described in the earlier section on lysimeter studies.

Annual and accumulated amounts of liquid digested sludge applied in 1968-77 to maximum-treated plots are shown in Table 2 along with the calculated dry weights of solids applied. About 3,000, 700, 180, and 140 kg/ha of Zn, Cu, Ni, and Cd (respectively) were accumulatively applied as constituents of sludge on maximum-treated plots.

Table 2. *Annual Digested Sludge Loading Rates and Total Accumulations on Maximum-Sludge-Treated Blount Silt Loam Plots Planted with Corn*

	Liquid sludge applied (cm)		Dry solids applied (mt/ha)	
Year	Annual	Accumulation	Annual	Accumulation
1968	17.1	17.1	51.52	51.52
1969	25.4	42.5	48.31	99.83
1970	22.9	65.4	52.67	152.50
1971	38.1	103.5	128.37	280.87
1972	12.7	116.2	25.61	306.48
1973	27.9	144.1	62.15	368.63
1974	17.8	161.9	48.72	417.35
1975	12.7	174.6	32.56	449.91
1976	17.8	192.4	54.44	504.35
1977	15.2	207.6	52.29	556.64

Results

Soils

Several chemical properties of Blount silt loam were changed by sludge applications. Changes in soil composition were similar to those measured on soils from lysimeter plots. Apparently, an equilibrium condition between additions and losses of N and C had been established by 1974, and concentrations at equilibrium depended on annual loading rates. Nothing indicated that total N and organic carbon concentrations below 30 cm were affected by sludge applications. Total P concentrations were increased at both the 0- to 15-cm and 15- to 30-cm depths of the soil by sludge applications.

Maximum and one-half maximum sludge applications resulted in significant corn grain yield increases in only 4 years out of 10. But they never decreased yields, and all sludge treatments resulted in significantly higher 10-year average grain yields than were produced with high rates of conventional inorganic fertilizers. The annual addition of large amounts of sludge resulted in increased concentrations of several elements in corn grain, as shown in Table 3. Only Zn and Cd were consistently increased in all tissues tested.

Continuous Soybeans on Plots of Blount Silt Loam

The main objective of this segment of the study was to determine how soil chemical changes produced by sludge applications affect soybean nutrition and chemical composition of plant tissues.

Three replications of 12.2- x 12.2-m plots in a random complete block were established on Blount silt loam in the fall of 1968 for the following depth of applications of liquid sludge: control (zero); maximum (25.4 mm); one-half maximum (12.7 mm); one-fourth maximum (6.4 mm). Well water was supplied at the same time and rate as the maximum sludge applications.

Only one application had been made in 1972 when the soybean seedlings on maximum-sludge-treated plots began to show symptoms of P toxicity. After severe P toxicity symptoms were observed, sludge applications were suspended until harvesting was completed in 1973. When P toxicity symptoms did not occur on soybeans growing on maximum-sludge-treated plots in 1973, sludge applications were resumed on plots, that in previous years had also received a broadcast application of superphosphate, to determine whether P toxicity would recur.

Soybean yields were increased by sludge application each year. Yield depression in 1972 and 1976 on maximum-sludge-treated plots was attributed to the P toxicity.

The concentrations of several elements in soybeans were increased by sludge application. Maximum sludge application frequently resulted in higher concentrations of N in leaves and petioles, but not in beans and stalks. Phosphorus was increased sometimes, but not in plants from plots where sludge applications were terminated in 1972. Concentrations of Zn, Cd, and Ni were significantly increased in all soybean tissues by annual applications.

Mine Spoil Study

In the spring of 1973, a continuous corn study was established on newly graded strip-mine spoil banks in Fulton County. For this study, sludge loading rates, application methods, replication of treatments, sample collection and handling, etc., were similar to those in the continuous study established in 1968 on the Northeast Agronomy Research Center. The main difference between the two studies was that the sludge used in Fulton County was pumped from holding reservoirs that stored the digested sludge barged from the Southwest wastewater treatment plant in Chicago. Major objectives of the study were (1) to assess the value of sludge as opposed to conventional fertilizer for improving strip-mine spoils for profitable rowcrop production, and (2) to compare uptake of inorganic elements by corn grown on sludge-

*Table 3. Concentrations of Zn, Ni, Cu, and Cd in Corn Grain from Sludge-Treated Field Plots on Blount Silt Loam *, †*

		(ppm) Sludge Treatment				
Constituent	*Year*	*0*	*One-fourth Maximum*	*One-half Maximum*	*Maximum*	*Least Significant Difference*
Zn	*1970*	*32*	*40*	*50*	*65*	*15‡*
	1971	*24*	*37*	*36*	*53*	*10‡*
	1972	*22*	*29*	*40*	*50*	*13‡*
	1973	*29*	*37*	*51*	*58*	*6‡*
	1974	*28*	*37*	*46*	*56*	*7‡*
	1975	*24*	*36*	*44*	*53*	*6‡*
	1976	*33*	*42*	*54*	*62*	*9‡*
	1977	*30*	*43*	*50*	*62*	*9‡*
Ni	*1970*	*1.6*	*1.6*	*2.1*	*3.1*	*1.0 §*
	1971	*0.7*	*1.2*	*1.4*	*4.0*	*1.7‡*
	1972	*0.6*	*0.8*	*1.3*	*2.2*	*0.4‡*
	1973	*1.2*	*0.9*	*1.3*	*1.7*	*0.4‡*
	1974	*1.4*	*1.6*	*1.9*	*2.0*	
	1975	*3.3*	*3.2*	*6.9*	*5.9*	
	1976	*0.6*	*0.6*	*1.0*	*1.6*	*0.4‡*
	1977	*0.5*	*0.4*	*0.7*	*2.0*	*0.9‡*
Cu	*1970*	*2.7*	*3.7*	*2.7*	*2.9*	
	1971	*2.4*	*2.6*	*2.2*	*2.0*	*0.4§*
	1972	*2.8*	*3.0*	*2.9*	*3.1*	
	1973	*2.4*	*2.6*	*2.6*	*2.0*	
	1974	*3.0*	*3.1*	*2.6*	*2.2*	
	1975	*2.1*	*2.1*	*2.2*	*2.0*	
	1976	*3.0*	*2.5*	*2.8*	*3.2*	
	1977	*2.0*	*2.2*	*2.1*	*2.4*	
Cd	*1970*	*0.30*	*0.60*	*0.79*	*1.00*	*0.20‡*
	1971	*0.14*	*0.70*	*0.65*	*0.92*	*0.40‡*
	1972	*0.14*	*0.45*	*0.83*	*1.10*	*0.52‡*
	1973	*0.08*	*0.15*	*0.35*	*0.61*	*0.06‡*
	1974	*0.09*	*0.18*	*0.04*	*0.81*	*0.22‡*
	1975	*0.06*	*0.17*	*0.28*	*0.51*	*0.08‡*
	1976	*0.09*	*0.26*	*0.42*	*0.84*	*0.13‡*
	1977	*0.07*	*0.25*	*0.60*	*0.92*	*0.22‡*

**Concentrations are on a dry weight basis.*
†Samples from plots identified in report as NW 800 series.
‡Significantly different at $P \leq .01$.
§Significantly different at $P \leq .05$.

amended-strip-mine silty clay loam with corn grown on sludge-amended Blount silt loam. Before plowing each spring, 336, 224, and 115 kg/ha of N, P, and K, respectively, were applied to control plots.

Maximum sludge applications produced significantly higher yields of corn grain than for the control plots in 3 of the 5 years, and the 5-year mean yields were also significantly higher. But the expected increase in corn yields with increased years of applying sludge did not occur, perhaps because of excessive tillage required to produce an adequate seed bed.

Except for Zn and Cd, sludge applications did not consistently produce significant changes in concentrations of the elements studied in corn tissues. Accumulations of Zn and Cd in strip-mine spoil appeared to affect tissue concentrations much more than they did in plots of Blount silt loam.

Special Studies

Uptake of Heavy Metals and P by Inbred Corn Lines and Crosses of Selected Inbred Lines

This study was conducted to determine differences in the accumulations of selected elements in leaves and grain of inbred corn grown on control plots and sewage-sludge-amended soil.

Twenty inbred corn lines commonly used as parents for hybrids adapted to the Corn Belt were planted in Blount silt loam (Aeric ochraqualf, fine illitic, mesic) with and without sludge. At the beginning of the 1976 growing season, maximum-sludge-treated plots had received a 7-year accumulative application of sludge solids (374 metric tons/ha, dry weight equivalent). During the growing season, 236 mm of sludge (71 metric tons/ha of dry solids) were applied on maximum-treated plots.

The six inbred lines in Table 4 are listed by Cd concentrations in grain from plants grown on maximum-sludge-treated plots.

The results suggest that variations in P and metal levels in corn leaves and grain are determined by heritable differences as well as by various concentrations available in soils for plant uptake.

Effects of Sludge Applications on Organic Fractions of Blount Silt Loam Soil

This study was undertaken to gain more precise information on the fate and nature of the organic fraction of anaerobically digested sludge in the soil environment. The studies were carried out using six Blount silt loam plots from the 44-plot lysimeter facility. Soil samples were collected in May 1975 to a depth of 76 cm. Leachate water samples from the plots were collected at the beginning of each drainage event occurring from May 1974 through April 1975.

The most striking change in soil composition resulting from sludge application was the increase in oil and grease. In the 0- to 15-cm depth, this fraction was increased from 1.67% to 11.93% of the total organic C. No poor growth resulting from oxygen deficiency has been observed, however, in these studies.

Biological Activity in Soils and Strip-Mine Spoil With and Without Sludge

When sludge from plants treating industrial wastewaters are applied to land, the ability of soil to bind heavy metals and accumulate them in plant rooting zones raises a serious question as to the influence of the more soluble metals on the biological activity in soils. The purpose of this work was to determine how the continuous heavy applications of digested municipal sludge to cropland affect the main systematic and physiological groups of soil microflora and enzymatic activity.

The data show consistent increases in total bacterial populations with high sludge application rates. In general, the response of total bacteria to sludge treatment at the maximum level was at lease a twofold increase.

Table 4. *Concentrations of Cd in Grain from Inbred Corn Lines Grown on Control and Sludge-Amended Blount Silt Loam Plots **

	(mg/kg) Sludge application rates		
Inbred	*0*	*Maximum*	*Least Significant Difference*
B37	*0.12*	*3.87*	*1.76†*
H98	*0.11*	*2.43*	*0.81†*
R802A	*<0.06*	*0.34*	*0.12†*
R177	*0.16*	*0.33*	*0.14†*
AB73	*0.09*	*0.15*	*0.05‡*
R805	*0.06*	*0.08*	*n.s. §*

* *Concentrations are ranked from highest to lowest uptake by inbred lines grown on maximum-sludge-treated plots.*

†,‡ *Significantly different at $P < 0.05$ and $P \leq 0.01$, respectively.*

§ *Not significantly different.*

Except for *Azotobacter*, no clear-cut evidence was found that microbial populations and their activities were restricted by sludge applications. The most popular explanation for a decrease in *Azotobacter* populations with higher sludge application rates is that they are unable to compete successfully with other organisms in the presence of abundant nutrient supplies.

Influence of Municipal Sewage on Mineralization of Plant Residues and Changes in Microbial Populations

Heavy metals have been shown to affect some microbiological processes in the soil. The purpose of this study was to determine the direct influence of metals in sludge on the mineralization of plant residues as compared with the indirect influence of metals accumulated by plants.

Based on data from the literature and findings from this study, it appears that the way metals affect the activity of microorganisms depends on the form in which the metals exist. Sludge mixed directly with plant residue did not have an inhibiting effect on the mineralization of organic C.

Physical and Chemical Changes in Sewage-Sludge-Amended Soil and Factors Affecting the Extractability of Selected Chemical Elements

Objectives of the study reported here were as follows: (1) Determine changes in chemical and physical properties of a soil that had been annually irrigated with anaerobically digested municipal sewage sludge during six successive growing seasons; (2) investigate changes in 0.1 *N* HCl and 2.5% CH_3COOH extractable quantities of P, Fe, Mn, Zn, Cu, Ni, Cr, Cd and Pb from control and sludge-amended soils; and (3) employing the same two acids, examine changes in extractable levels of the previously listed elements in soil samples adjusted to different moisture contents and incubated at different soil temperatures.

On maximum-sludge-treated plots, accumulated solids (dry weight equivalent) incrementally applied during the 6 years amounted to 369 metric tons/ha in 1974.

The incorporation of 369 metric tons/ha of dry solid residuals of liquid sludge suspensions applied by furrow irrigation on Blount silt loam in more or less equal increments over a period of 6 years caused significant increases in several plant nutrient and non-nutrient elements. Soil contents of organic C and total N were increased more than twofold. The C to N ratios were 11.5 and 11.7, respectively, for control and sludge-amended plots; thus, they were not significantly different. Sludge applications caused a 4.4-fold increase in total P. Except for Fe and Mn, soil contents of all heavy metals were significantly increased by sludge applications. On a proportional basis, Cd was increased to the greatest extent. Potassium, Mg, and Na contents were about the same in control and sludge-amended soils. Liming of soils probably was the major cause of differences in Ca levels.

The pH was not significantly different for control and sludge-amended soils. Relatively high annual applications of digested sludge caused a significant increase of 2.5 meq/100 g in soil cation exchange capacity. Exchangeable concentrations of several heavy metals were higher in sludge-amended soils, but total exchangeable concentrations as a percent of cation exchange capacity were not significantly different. Digested sludge applications increased the total water-holding capacity (moisture content at 1/3 atmospheres air pressure) of the soil, but available water holding capacity (moisture content at 1/3 atmosphere less content at 15 atmospheres) was unchanged.

Animal Studies

Selected Chemical Elements in Tissues of Pheasants Fed Corn Grain Produced on Sewage-Sludge-Amended Soil

The feeding of corn (*Zea mays* L.) grain produced by the use of sewage sludge as a fertilizer was initiated in the winter of 1973 using pheasants (*Phasianus colchicus*) as test animals. Total sludge applied during the 6 years (1968 through 1973) on each maximum-treated plot amounted to 369 metric tons/ha (dry weight).

Sludge application significantly increased concentrations of Zn, Cd, Ni, K, and P in corn. But only Cd was significantly increased in birds, and only in duodenal, liver, and kidney tissue when the grain was fed to pheasants. Cd was not increased in muscle tissue. Concentrations did not exceed the range that is normal for wild pheasants. No correlation was shown between chemical composition of the grain and weight changes of the birds, or in the amount of grain they consumed.

Effects of Sewage-Sludge-Fertilized Corn on Growing Swine

In 1974, corn grain was harvested from the control and sludge-amended plots of the long-term, continuous corn study that was initiated in 1968. Corn harvested from these plots after 6 years of sludge treatment was ground and incorporated as 79.4% of a standard swine ration formulated for 16% protein.

Measurements of potential manifestations of toxicity (e.g., electroencephalography, electrocardiography, clinical chemistry, hematology, and histopathology) were conducted by recognized specialists using standard techniques.

The groups on sludge-fertilized corn generally outperformed the control group, but the differences were not statistically significant. Concentrations of several chemical elements were determined in samples of liver, spleen, kidney, muscle, brain, and bone from swine assigned to the three feeding regimens. Only concentrations of Cd were increased, and only in liver and kidney tissues ($P \leq 0.05$) as a result of feeding corn grain having elevated levels of Cd. Neither electrocardiagrams, electroencephalograms, clinical chemistry, nor histopathological studies indicated problems from short-term feeding of corn from fields fertilized with sludge from a large industrial city. Some interference with glucose metabolism and microsomal mixed-function oxidase activity was indicated, but the study indicated that short-term feeding of corn fertilized by stabilized municipal sludge did not impair the health or performance of swine.

Effects of Overwintering Pregnant Swine on Soils Heavily Amended With Municipal Sewage Sludge

To simulate a "worst-case" study, 16 weanling purebred Berkshire gilts were assigned to the long-term continuous corn plots. The gilts were introduced to the plots on November 4, 1975, and removed on March 20, 1976. They farrowed in October and returned to the same plots as sows on December 2, 1976. The sows were again bred in January while on the plots, removed from the plots on March 15, 1977, and farrowed in the spring of 1977. The sows were terminated for examination after the second litter was weaned.

No dose-related differences existed in metal concentrations in muscle, heart, or lung tissues. But a significant increase occurred in Cd concentrations of the pancreas, spleen, liver, and kidney.

Conclusions

Concentraions of NH_4-N, P, K, Na, Zn, Cu, Ni, Cd, Cr, total solids, organic-C, and electrical conductivities of runoff and drainage waters from sludge-treated lysimeter plots were frequently higher than those of similar samples from control plots. Concentrations of NO_3-N were markedly increased in drainage water and, to a smaller extent, in runoff water. Soil concentrations of several chemical elements also increased, but P-toxicity in soybeans was the only phytotoxic condition produced by excessive sludge loading rates applied each year. Effects of P-toxicity were evident only during the first year after sludge applications were terminated. Metal concentrations in corn and soybean tissues, and especially in corn grain, decreased rapidly following the termination of sludge applications. Uptake of metals by corn grown on three soil types with very different cation exchange capacities was about the same from plots that had received similar sludge treatments.

Testing of inbred cornlines and their progeny demonstrated that the capacity to exclude Cd from the aerial parts of plants is an inherited characteristic. This result suggests that metal uptake could be controlled through plant breeding. Analyses of dry-milled corn grain and wheat showed that major portions of Cd and other inorganic elements were contained in those fractions used as animal feedstuffs.

Applying sludge each year for 10 years on continuous corn plots improved soil physical properties and never adversely affected seed germination. Organic matter in sludge is mineralized within a few months after incorporation into soils, and an equilibrium between ammonia added and amounts lost each year is approached in 3 to 4 years. Sludge application to soil appeared to have no deleterious effect on soil microbial populations and enzyme activity.

When sludge is used at agronomically appropriate rates, the risks of adverse health effects on humans or livestock are minimal. But when digested sludge is used as a soil amendment at rates that greatly exceed those needed to optimize fertility, the possibility does exist that trace elements may be absorbed and transported into plant tissues in amounts that may be harmful to animals. No evidence was found, however, that Cd accumulated in corn grain will result in an animal health problem.

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The complete report, entitled "Effects of Using Sewage Sludge on Agricultural and Disturbed Lands," (Order No. PB 84-117 142; Cost: $43.00, subject to change) will be available only from:
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