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Project Summary

Long-Term Use of Sewage Sludge on Agricultural and Disturbed Lands

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Results are presented from two reports on field studies done during a 15-year investigation of the long-term use of sewage sludge on agricultural and disturbed lands. These projects are intended to answer concerns about how sludge applications to soils relate to phytotoxic accumulations of trace metals and hazardous metal levels in crops. Studies were conducted on plots at the Northeast Agronomy Research Center near Elwood, Illinois at the University of Illinois, Urbana, and on strip-mined land near Canton, Illinois owned by the Metropolitan Sanitary District of Chicago.

The first study, entitled "Use of Sewage Sludge on Agricultural and Disturbed Lands," reports the results of the following field studies: (1) response of corn on three soil types previously amended with annual sludge applications, (2) response of continuously planted corn on Blount silt loam to repeated annual applications of sewage sludge, (3) response of winter wheat and soybeans on Blount previously amended with annual applications of sludge, (4) sludge-amended strip-mine spoils continuously planted with corn, (5) differences in Cd and Zn uptake by various corn hybrids, (6) effects of cation exchange capacity on Cd uptake, (7) uptake of metals by spinach from Cd-spiked sludge, (8) response of chickens to Cd in feed, and Cd-induced growth depression and Cd accumulation in chicks as influenced by dietary modifications. The second study entitled "Long-Term Use of Sewage Sludge on Agricultural and Disturbed Lands," reports on the following field studies: (1) the response of corn to repeated annual applications of sewage sludge, (2) the differential uptake of selected corn hybrids grown on sludge-amended soils, and (3) the effects of high sludge application rates on strip-mine spoil characteristics and the response of plants.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research projects that are fully documented in two separate reports (see Project Report ordering information at back).

Introduction

Digested sewage sludge is an effective source of N and P for the fertilization of field crops. When applied at rates sufficient to provide recommended rates of supplementary nitrogen for nonleguminous crop plants, sewage sludge also supplies relatively large amounts of organic matter. Thus long-term use of sludge changes the physical properties of some soil types to such an extent that crop yields frequently exceed those obtainable with commercial fertilizers. Agricultural use of sewage sludges eliminates the high energy costs, potential air pollution, and ash disposal problems encountered by sludge incineration. But sewage sludges contain trace elements in concentrations that often greatly exceed normal concentrations in productive soils. Many environmentalists are therefore concerned that heavy metals and metalloids may accumulate and eventually reach phytotoxic levels. Some are con-

cerned that concentrations of certain trace elements may be enhanced in food and feed stuffs enough to present a health hazard to man and animals.

The two reports summarized here contain the results from segments of a 15-year investigation of the long-term use of sewage sludge on agricultural or disturbed lands. Studies were conducted at the Northeast Agronomy Research Center near Elwood, through the University of Illinois at Urbana, and on Chicago MSD strip-mined land near Canton, Illinois. The purpose of the work reported here was to determine how sludge applications to soils relate to phytotoxic accumulations of trace metals and hazardous metal levels in crops. The first study, entitled "Use of Sewage Sludge on Agricultural and Disturbed Lands," presents the results from eight field studies. These include investigations of corn responses to various soils previously or currently amended with annual sludge applications, corn responses to sludge-amended strip-mine spoils, differences in Cd and Zn uptake by various corn hybrids, effects of cation exchange capacity (CEC) on Cd uptake, metal uptake by spinach from soil amended with sludge with and without additions of $CdCl_2$ and response of chickens to biologically incorporated Cd in feed. The second study, entitled "Long-Term Use of Sewage Sludge on Agricultural and Disturbed Lands," discusses the result of field studies on the response of corn to repeated annual applications of sewage sludge, the differential uptake of Zn in two selected corn hybrids grown on sludge-amended soils, and the effects of high rates of sludge applications on strip-mine spoil characteristics and the response of plants. Each report is summarized briefly here.

Use of Sewage Sludge on Agricultural and Disturbed Lands

This report presents the results of 8 field studies, which are described as follows:

Response of Corn on Three Soil Types Previously Amended with Annual Applications—This field study was conducted to determine the changes in metal uptake by corn after annual applications of sewage sludge had ceased. The study was conducted on lysimeter plots containing 3 contrasting soil types on which sludge had been applied annually for 5 years (1969-73) at 3 different rates—maximum, half the maximum, and one-fourth the maximum. Control plots were fertilized and irrigated. After 1973, sludge applications were discontinued on all Blount silt loam plots and on all Elliott silt loam and Plainfield sand plots except those that had received maximum sludge applications. On maximum-sludge-treated Blount plots, the sludge applied per hectare was equal to 232.5 mt solids, 8,044 kg P, 58.3 kg Cd, and 1,290 kg zn. After sludge applications were discontinued in 1976 on maximum-sludge-treated plots of Elliott silt loam and Plainfield sand, the sludge added per hectare was equal to 423 mt solids, 14,785 kg P, 112.7 kg Cd, and 2,167 kg Zn.

Yields of corn grain on Blount plots varied directly with the annual rate of sludge application. After applications ceased, residual sludge N in soil was adequate to maintain corn yields for 3 years without decline. When nitrogen fertilizer was applied in 1979, yields returned to the average levels for the 10-year period.

After sludge applications were terminated, Cd and Zn levels in corn plant tissues decreased with time. Relatively speaking, Cd in corn grain decreased more rapidly than Zn. The greater the level of Cd accumulated in soils through additional incremental annual sludge applications, the more time was required for Cd to decrease to background levels. The availability of Cd and Zn for uptake by corn decreased by about 50 percent during the first year after sludge applications were suspended; thereafter, it declined more slowly.

Response of Continuously Planted Corn on Blount Silt Loam to Repeated Annual Applications of Sewage Sludge—The purpose of this study was to determine the long-term benefits and adverse environmental effects of sludge use on land. Before this 3-year study, sludge had already been applied to field plots for 10 years at 3 rates (maximum, half the maximum, and one-fourth the maximum). Data in Table 1 show the amounts of sludge applied annually during the study (1978-80) and the accumulated total of sludge applied over 13 years.

N and P applied to plots averaged about 10, 5, and 2.5 times the amount needed for an optimum corn crop on maximum, half maximum, and one-fourth maximum-sludge-application plots, respectively. After 1980, the following additions of metals to soil had been applied (kg/ha):

Cd	185	Ni	264
Cu	1018	Pb	768
Cr	2186	Zn	3652

Table 1. Sludge Applied Annually and Accumulated Over the 13-Year Period on Maximum-Sludge-Treated Blount Silt Loam Corn Plots

	Dry Solids Applied (mt/ha)	
Year	Annual	Accumulated Since 1968
1978	68.4	625.0
1979	62.5	687.5
1980	45.8	733.3

Chemical composition of the surface soil was changed by the 13 years of annual sludge application. The first 0- to 30-cm were enriched by organic C and total N, though the soil level appeared to have reached equilibrium. Concentrations of P and heavy metals were greater than in control plots to a depth of 30 cm; but K, Na, Ca, Mg, and Mn concentrations were essentially unaffected by sludge addition. Levels of Cd, Cu, Cr, Ni, Pb, and Zn were significantly increased to a depth of 30 cm.

Only concentrations of Cd, Cu, Ni, and Zn were consistently increased in leaves, grain, and stover of corn. Plots were split in 1980, half of each plot was planted with a hybrid variety that had been grown in each of the 13 study years but that would be unavailable in the future. The other half of each plot was planted with a new variety that accumulated only about half as much Cd (Table 2). No phytotoxicity was apparent in the 3-year period.

Response of Winter Wheat and Soybeans to Residual Sludge in Blount After Annual Sludge Applications Cease—Studies were conducted to determine whether metal uptake by soybeans and wheat would decrease as the metal in the soil reverted to a less available form or whether the uptake would increase as organic matter decomposed.

Soybeans were grown from 1969 to 1976 on plots that had received sludge applications at 3 rates since 1969. Control plots were fertilized and irrigated with water. Plots were split so that half of each received extra P (118 kg/ha). Sludge applications were continued on the P-treated halves when P toxicity became evident in 1972, but they were discontinued on the untreated halves. The total of sludge solids that had accumulated on the maximum sludge plots was then 242 mt/ha. The P-treated halves continued to receive sludge and grow soybeans until 1976, when toxicity again affected the crop. The total sludge that had been

Table 2. Average Concentration of Cd in Corn Grain and Stover from Two Hybrids Planted on Plots of Blount Silt Loam

Item and Year	(mg/kg dry weight) Sludge Treatment: No Sludge (Control)	One-fourth Maximum	Half Maximum	Maximum	LSD
Cd in Corn Stover					
Pioneer 3517					
1978	*1.1*	*6.7*	*13.3*	*27.8*	*6.3**
1979	*0.9*	*10.5*	*25.9*	*42.7*	*11.3**
1980	*0.7*	*7.5*	*26.6*	*36.9*	*11.5**
Pioneer 3541					
1980	*0.484*	*3.76*	*8.61*	*14.1*	*2.46**
Cd in Corn Grain					
Pioneer 3517					
1978	*0.09*	*0.18*	*0.46*	*0.68*	*0.20**
1979	*<0.06*	*0.25*	*0.43*	*0.72*	*0.20**
1980	*<0.06*	*0.32*	*0.57*	*0.73*	*0.19**
Pioneer 3541					
1980	*<0.062*	*<0.062*	*0.111*	*0.171*	*0.086**

**Significant difference at P 0.01.*

added to the maximum sludge plots was then 411 mt/ha.

Wheat was grown on all plots in 1977, 1979, and 1980. Soybeans were grown in 1978 because of a wheat failure.

Six years after sludge application ceased, concentrations of Cd and Zn were still higher in soybeans from sludge-treated plots than they were in beans from control plots. Cd and Zn concentrations in wheat did not decrease for 8 years after sludge applications stopped, but Ni and Cu gradually returned to background concentrations.

Sludge-Amended Strip-Mine Spoils Continuously Planted with Corn—Beginning in 1973, digested liquid sewage sludge was applied at 3 rates by furrow irrigation to neutral or calcareous strip-mine spoils continuously planted to corn. This study plan was similar to that of the long-term effects studies on Blount silt loam. The maximum-sludge-treated plots had received a total of 248 mt/ha by the end of 1977, and 64.3 and 79.6 mt/ha were applied in 1978 and 1979, respectively.

Cd and Zn accumulations in corn plant tissues increased as sludge accumulated in the spoil, whereas uptake on the Blount plots appeared to be more directly related to the annual application of the previous year. Corn grain and stover yields were low when compared with yields from sludge-treated Blount plots. The reason is thought to be the compaction of the fine-textured spoils during grading and tillage operations.

Air-dried sludge (45 percent moisture) was applied to strip-mine spoils to compare the site management problems and the effects of large, single applications of dried sludge with the incremental applications of liquid digested sludge. The study was also conducted to identify plants that would rapidly establish a vegetative cover and to select cropping systems that would minimize erosion. Replicate plots were treated with sludge at rates of 224, 448, and 896 mt/ha. Fertilized control plots were also replicated. Corn, wheat, rye, and 11 species of forage grasses were grown on the plots. The effects of sludge rates on chemical and physical properties of the spoil and on crop yield and composition were measured.

Trace elements moved deeper into the calcareous spoils than they did in the acid Blount silt loam. Cu, Cd, and Pb moved below the 18-cm depth of mixing, but they did not reach below 60 cm. Mg, P, Mn, Cd, Ni, and Zn increased in corn, wheat, and rye grain after sludge application. Yields increased with sludge applications up to 448 mt/ha, but they decreased at 896 mt/ha rate. Cd uptake was also similar at the intermediate and high application rates. High single applications may produce better crops than the same amount of sludge applied in annual increments if NO_3 leaching can be controlled. The highest sludge application rate produced lower corn yields than the lowest rate (224 mt/ha) because of soluble salts.

Differences in Cd and Zn Uptake by Various Corn Hybrids—In an earlier study, 20 inbred corn hybrids were screened to determine their different capacities for accumulating Cd and Zn when grown on sludge-amended Blount silt loam plots. The inbreds varied greatly in Cd capacity—some by as much as a factor of 10.

Two commercially available corn hybrids were selected to determine whether the Cd- and Zn-accumulating characteristics of their parent inbreds would be transmitted to the single-cross hybrids. Results from the field study showed that selected hybrids were indeed different when grown on split plots that had been annually irrigated with sludge during the 9 years before the present 3-year study. Cd concentrations in grain from the low-Cd hybrids grown on maximum-sludge-treated plots were lower than those in grain from the high-Cd-accumulator grown on control plots, except in the first year of the study. Cd concentrations in grain from the low-Cd-accumulator never exceeded the upper range of normal background levels in grain, even though annual sludge applications were continued throughout the study period. During the last year of the study, the Cd concentration in grain from the low-Cd-accumulator grown on maximum-sludge-treated plots was not significantly different from concentrations in grain from control plots. The uptake of other chemical elements by the two hybrids was independent of their inherited capacity to take up or exclude Cd.

Effects of Cation Exchange Capacity on Cd—The object of this study was to determine the importance of cation exchange capacity (CEC) of soils in regulating Cd uptake from soils treated with sludge and with $CdCl_2$.

Three soils were mixed in various ratios to achieve CEC values of about 16, 11, and 5 Meq/100 g of soil. Cadmium was applied either as a sludge or as $CdCl_2$ in the greenhouse. Corn was grown, and the uptake of Cd was measured after 3 weeks in half of the plants and 7 weeks in the remaining plants.

Cd uptake from $CdCl_2$-treated plots was invariably inversely proportional to the CEC of the soils, but the uptake from sludge-treated plots was not affected by CEC. CEC from organic matter more effectively prevented plant uptake of Cd

from $CdCl_2$ than CEC due to inorganic soil components. Sludge properties appeared to be an important factor in the control of Cd uptake when Cd-bearing sludge was applied to the soil.

Uptake of Metals by Spinach from Cd-Spiked Sludge—A greenhouse study was designed to determine whether plant uptake of Cd from sludges differed when the latter were spiked with Cd salts instead of containing the equivalent amount of indigenous Cd. Ten different sludges were used, with pairs containing Cd levels of 40, 140, 400, 600, and 1000 mg Cd/kg sludge solids. For the first four Cd levels, all of the Cd was indigenous to the sludge in one of each pair. But at the highest level, indigenous Cd had to be supplemented with $CdCl_2$ to achieve the desired concentration.

The study indicated that spinach (an accumulator of Cd) had higher concentrations of Cd when grown with the Cd-spiked sludge than when grown with the sludge containing indigenous Cd in the same concentrations.

Response of Chickens to Cd in Feed—Because egg-laying hens consume larger amounts of feed per unit of body weight than other domestic animals, chickens were fed high-, medium-, and low-Cd diets to determine possible adverse effects of Cd-enriched feed grown on sludge-amended strip-mine spoils. High- and intermediate-Cd-accumulating corn hybrids were grown on spoils amended with Chicago sludge. Concentrations for the high-, medium-, and low-Cd diets were 0.71, 0.35, and 0.06 mg Cd/kg corn, respectively. Soybean cultivars that took up different amounts of Cd were also grown on sludge-amended spoil and their meal was mixed with the high-Cd corn meal to produce feeds containing 2.38, 1.22, and <0.06 mg Cd/kg.

Three hundred pullet chicks were separated into lots of 25 each and fed a starter diet. At 8 weeks, the diet was changed to a developer diet, and at 20 weeks to an egg-laying diet. The birds were housed in laying cages, with 2 birds in each cage. High-, medium-, and low-Cd diets were each fed to four lots of birds (i.e., there were 4 replications of birds on each diet). When birds were sacrificed, Cd was found in the crop, proventriculus, muscular gizzard, gizzard lining, duodenum, liver, kidney, pancreas, and spleen tissues in proportion to Cd in the diets. Concentrations of Cd in leg muscle, breast muscle, and femur bone did not vary with diet levels. When dietary Cd was decreased, Cd decreased in all accumulatory tissues except the kidneys. Eggs did not accumulate Cd in proportion to the dietary level of the metal. Nothing indicated that the health, body weight gain, or egg production of the chickens fed the high-Cd corn and soybeans were affected.

Cd-Induced Growth Depression and Cd Accumulation in Chicks as Influenced by Dietary Modifications—Nine experiments were conducted with 1-week-old, cross-bred, meat-type chicks to explore the effects of dietary nutrient balance on the response of chicks to Cd. The element was added to their corn-soya feed as $CdCl_2$ in incremental doses over a period of 2 weeks. At 10 ppm, growth depression occurred, and Cd content of kidneys and livers increased as a result of the added Cd. As the Cd intake was increased, the percent of ingested Cd retained in the liver and kidneys also increased.

Simultaneous decreases in dietary Cd, Zn, P, and Mn increased the growth sensitivity of chicks to added Cd and increased Cd retention without affecting growth when no Cd was fed. When the diet was adjusted to be marginal in methionine and Mn, supplementing the diet with either of these nutrients did not influence growth or Cd retention when Cd was added to the diet. Added Cu did not alleviate Cd-induced growth depression, but it did increase Cd retention. Supplemental Zn and Ca levels above accepted requirements ameliorated Cd-induced growth depression and reduced the amount of Cd retained in livers and kidneys.

Chicks depleted of vitamin D during the first week of life were found to be more growth-sensitive to 10 ppm Cd in subsequent 2-week assays. High levels of vitamin D reduced the growth depression and increased liver and kidney accumulation of Cd in both vitamin-D-depleted and undepleted chicks. When levels of Ca and vitamin D that were marginal for maintaining normal bone ash were fed, 10 ppm of added Cd reduced tibia bone ash.

Conclusions—The conclusions from the eight field studies are:

1. A phytotoxic condition is not likely to develop as a result of the repeated use of the Chicago sludge as a fertilizer.
2. The high pH of calcareous spoil failed to control the uptake of Cd and Zn by corn to levels lower than those observed on acid Blount silt loam.
3. A one-time sludge application of about 200 mt/ha may produce better quality grain and forage than could be obtained with an equivalent amount of sludge applied over several years at rates to supply recommended amounts of N. But special precautions will be required to protect ground water against contamination with NO_3-N where one-time, high-rate sludge applications are made.
4. Data from this study show that regardless of the nature of the mechanism, the losses of sludge-borne heavy metals from soils occur rather rapidly, and the amounts remaining for uptake by plants decreases with time and are not affected by applications of inorganic sources of N.
5. The decrease in uptake of residual metal concentrations in soil from previous sludge applications varies with differences in crop species and probably with varieties within a particular species.
6. Enhancement of heavy metal concentrations in food and feed stuffs can be controlled by plant breeding.
7. Data from studies involving the use of soluble Cd salts are of little value in predicting Cd uptake by plants grown on sludge-amended soils.
8. At the highest level of Cd that could be biologically incorporated in corn grain and soybeans produced on sludge-amended fields, nothing (body weight changes, egg production, or various clinical parameters) indicated that the enhanced levels of dietary Cd affected the health of the chickens.
9. Since the highest possible level of biologically incorporated Cd in feed did not increase levels of the metal in egg shells, whites, yolks, muscle tissues, or bones, the probability of increasing Cd in human foods to harmful levels is very low.

Long-Term Use of Sewage Sludge on Agricultural and Disturbed Lands

This report describes the results of 3 field studies conducted during the last 2 years of the full 15-year investigation. Each field study is described here briefly along with conclusions and recommendations.

Corn Response to Continuous Annual Sludge Applications—The purpose of this study was to investigate the cumulative effects of the 14 consecutive years of applying digested liquid sludge from Chicago to 4 plots, each 6.1 by 12.2 m (20

by 40 ft). The plots were treated with liquid sludge in furrows at 3 rates—31.8 (Table 3), 15.9, and 7.95 Mt solids/ha (maximum, half the maximum, and one-fourth the maximum rate). The sludge-treated plots received 134 kg/ha of supplemental K as KCl_2. Control plots were fertilized with commercial fertilizer. Corn was planted to produce 60,000 plants/ha.

The amounts of various sludge constituents applied in 1981 and over a 14-year period on maximum-sludge-treated plots are listed in Table 4.

Metal concentrations in soil deeper than 30 cm (12 in.) had been slight or undetectable, so only samples from 0- to 15-cm and 15- to 30-cm depths were analyzed in 1981. Organic C and N increased to a depth of only 15 cm. As application rates increased, P, Zn, Cd, Cu, Ni, Cr, and Pb increased significantly to a depth of 15 cm; but concentrations of K, Na, Ca, Mg, Fe, and Mn did not significantly increase.

Plant populations and corn yields were not signficantly different for various application rates or for fertilized control plots, though 1981 yields were higher than the average for the 14 years. Thus 14 years of high-rate applications of Chicago sludge did not impair corn growth or yield even on an acid soil.

Sludge application increased the concentrations of only Cd and Zn in all corn tissues. But Cd concentration increased significantly more in the grain of the old hybrid (Pioneer 3517) than that of the new hybrid (Pioneer 3541) (1.06 compared with 0.18). The new hybrid growing on plots that had received optimum sludge applications to supply N annually for 14 years did not exceed the Cd concentrations expected for conventionally fertilized fields (0.06 mg Cd/kg corn grain). Neither Cr nor Pb were significantly increased in corn tissues after 14 years of sludge application. Low but statistically significant increases in Cu and Ni were found in corn tissues produced on plots treated with the two higher sludge loading rates.

Accumulations of Zinc by Corn Hybrids Grown on Blount Silt Loam Amended with Sewage Sludge—The purpose of this study was to determine the constancy of differential uptake of Zn between two selected corn hybrids grown under field conditions on sludge-treated soils. (A previous study had shown a consistently significant difference in Cd uptake between hybrids chosen as high- and low-Cd accumulators, but the uptake of Zn was not correlated closely with Cd uptake.)

Field plots of Blount soil that had received annual sludge application since 1969 (with a high accumulation of 648 mt/ha) were split and hand planted with two corn hybrids. Single-cross H99XW64A was a low-Zn accumulator, and A619XA632 was a high one. During 1981, an additional 12.7 cm, or 36.5 mt/ha of solids were applied as liquid digested sludge in furrows. At the beginning of the Zn study, more than 2900 kg Zn/ha had been applied on maximum-sludge-treated plots, and an additional 105 kg Zn/ha was applied in 1981.

Corn grain and stover yields indicate that sludge applications increased grain yields only in the hybrid selected for its potential capacity to take up small amounts of Zn. But the hybrid selected for its capacity to take up large amounts of Zn produced higher grain yields at all rates than did the low-Zn accumulator. Differences in stover yields were not significant between the two hybrids. Concentrations of Cu were increased more in the low-Zn hybrid.

Changes in Strip-Mine Spoil Characteristics and Response of Plants to High-Rates of Sewage Sludge Application—The purpose of this study was (1) to identify plants that can be established quickly on strip-mine spoils amended with one large application of dried sludge, and (2) to determine feasible one-time loading rates for sludge.

Air-dried sludge was applied in 1979 at rates of 224, 448, and 896 mt/ha on replicated 21- x 18-m plots. Big blue stem, orchard grass, perennial ryegrass, red top, reed canary grass, smooth brome, tall fescue, timothy, and western wheat grass were sown in 3- x 6-m subdivisions of the large plot. Two additional plots (6- x 8-m) were planted with corn.

Organic C and N content of the spoil declined only slightly during the 3-year study, indicating that the lagoon sludge used was very stable. Along with C and N, total concentrations of P, Ca, Mg, Fe, Zn, Cd, Cr, Cu, Ni, and Pb were significantly increased in the spoil in proportion to sludge loading rates. Little change was indicated in soil properties below 30 cm, except for a small pH change to a depth of 45 cm. Sludge applications increased the concentration of N, Zn, Mn, Ni, Cd, and Cu in corn plant tissues as they had in the first 2 years. Generally, sludge applications resulted in grasses enriched in Mg, P, N, Zn, Ni, Cd, and Cu, but they did not

Table 3. Annual Digested Sludge Loading Rates and Total Accumulations on Maximum-Sludge-Treated Blount Silt Loam Plots Planted to Corn

Year	Liquid Sludge Applied (cm)		Dry Solids Applied (mt/ha)	
	Annual	Accumulations	Annual	Accumulations
1968-1980	--	253.3	--	733.3
1981	10.2	263.5	31.8	765.1

Table 4. Amounts of Various Sludge Constituents Applied to Maximum-Treated Blount Silt Loam Plots Planted to Corn

Total	Percent Solids	Sludge Constituent												
		P	K	Na	Ca	Mg	Fe	Mn	Cd	Cu	Cr	Ni	Pb	Zn
Annual mean applied in 1981 (mg/L, wet weight)	3.14	890	232	104	1,012	468	1,500	6	5.7	48	72	15	22	94
Total amount applied during 1968-81 (kg/ha, dry weight)	--	23,589	3,997	--	25,269	9,725	33,305	344	191	1,067	2,259	279	790	3,748

affect concentrations of Ca, Cr, and Pb. The grasses that were easy to establish and that produced the highest yields on spoils treated with a high-rate loading of dried sludge were tall fescue, reed canary, orchard, and brome grass.

Conclusions—After 14-years of applying digested sludge on Blount silt loam soil (NW-800 series), no evidence suggested that a phytotoxic condition was imminent. Concentrations of Cd, Cu, Ni, and Zn were consistently enhanced in the leaf, grain, and stover of corn grown on sludge-amended plots, but there was little evidence that repeated annual applications of these sludge-borne metals significantly increased the accumulation of these metals in the above-ground parts of corn. The probable reason is that, despite the continued addition of sludge, metal levels in the soil did not increase. Relative to the amounts of metals applied, those migrating to depths below 30 cm were negligible. Since erosion was also negligible on these nearly level plots, it appears that several sludge constituents, including transition and heavy metals, were lost by unidentified processes either before the sludge was incorproated into the soil or immediately thereafter.

In a single season study, a single-cross corn hybrid with an inherited capacity to take up large amounts of zinc produced higher grain yields and tended to accumulate less Cu in above-ground plant parts than the low-Zn accumulator when grown together on maximum-sludge-treated plots. This important finding needs verification by repeating the experiment for different soils and growing years.

As compared with sludges drawn directly from digesters, digested sludge dredged from storage lagoons contained lower organic-C concentrations and higher metal contents. After sludge was incorporated into calcareous strip-mine spoil, the initial increased organic-C and metal contents in the 0- to 15-cm depth of spoil never decreased during the 3-year study. Thus the organic matter remaining in this sludge was very resistant to microbial decomposition in strip-mine spoil. Corn growth on mine spoil amended with high rates of this dewatered, stable sludge had markedly less uptake of sludge-borne Cd and Zn than did the same corn hybrid grown on plots treated with less stable sludge that was incrementally applied over several years on similar spoil material. This difference occurred in spite of the fact that total concentrations of Cd and Zn were eight times higher in the spoil amended with the one-time, high-rate sludge application.

Recommendations—The following recommendations are based on the findings presented in this report:

1. Further work should be done to determine the pathways by which transition and heavy metals were lost when liquid digested sludge was repeatedly applied on soils for several years.
2. Further work should be done to determine whether or not the transition and heavy metals remaining in soils will continue to be lost after sludge applications are terminated.
3. Further work should be done to determine why transition and heavy metals incorporated in strip-mine spoil as constituents of a dewatered and very stable sludge (as judged by its organic-C contents) were not lost and were considerably less available for uptake by plants.
4. Further work should be done to select species and develop varieties of grain and forage plants that would insure minimal uptake of sludge-borne Cd, and maintain the potential for high yields of crops with adequate concentrations of essential trace elements for animals in the plant parts used as feedstuffs.

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This Project Summary covers two separate reports, entitled:
"Long-Term Use of Sewage Sludge on Agricultural and Disturbed Lands," (Order No. PB 84-224 427; Cost: $11.50)
"Use of Sewage Sludge on Agricultural and Disturbed Lands," (Order No. PB 84-224 419; Cost: $22.00)
The above reports will be available only from: (cost subject to change
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