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USE OF SEWAGE SLUDGE ON AGRICULTURAL AND DISTURBED LANDS

by

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Grant No. R805629

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16. ABSTRACT

Results of 8 field studies of long-term use of digested sewage on agricultural and disturbed lands are presented. The studies included: (1) response of corn grown on 3 soil types previously amended with annual sludge applications; (2) response of corn grown annually on Blount silt loam treated annually with sludge; (3) continuous corn on strip mine spoils treated with sludge; (4) differences in Cd and Zn uptake by various corn hybrids; (5) effects of cation exchange capacity on Cd uptake; (6) Cd uptake from Cd-spiked sludge by spinach; (7) response of chickens to Cd in feed; (8) Cd-induced growth depression and Cd accumulation in chicks as influenced by dietary modifications.

No phytotoxicity developed from trace elements in sludge used annually as fertilizer. Crop uptake of heavy metals from soils containing residual sludge varied with species and varieties. Elevated levels of dietary Cd did not affect health of chickens, egg protection, nor composition of the eggs.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

This report presents results of a continuing long-term study of methods of recycling wastewater sludge on land. It contains information about beneficial and adverse effects of applying sludge on various kinds of soil at variable rates and indicates management needed to achieve the greatest benefit with low degree of risk to the environment or public health.

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Director
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ABSTRACT

Results are presented from eight field studies done during a 15-year investigation of the long-term use of sewage sludge on agricultural and disturbed lands. These projects were 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 at the Northeast Agronomy Research Center near Elwood, Illinois.

Field studies examined the following subjects: (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) sludge-amended strip-mine spoils continuously planted with corn, (4) differences in Cd and Zn uptake by various corn hybrids, (5) effects of cation exchange capacity on Cd uptake, (6) uptake of metals by spinach from Cd-spiked sludge, (7) response of chickens to Cd in feed, and (8) Cd-induced growth depression and Cd accumulation in chicks as influenced by dietary modifications.

Results showed no evidence that a phytotoxic condition was likely to develop as a result of the repeated use of the Chicago sludge as a fertilizer. Losses of sludge-borne heavy metals from soils occurred rather rapidly by an unknown mechanism. The availability of residual metal concentrations in soil from previous sludge applications varied with different crop species and varieties. Enhancement of heavy metal concentrations in food and feed stuffs can be eliminated by plant breeding. Enhanced levels of dietary Cd did not affect the health of chickens or increase the levels of the metal in egg shells, whites, yolks, muscle tissues, or bones.

This report was submitted in fulfillment of grant No. R805629 by the University of Illinois and the Metropolitan Sanitary District of Greater Chicago under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1977 to December 1980.

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SECTION I

INTRODUCTION

Digested sewage sludge is an effective source of nitrogen and phosphorus 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 high amounts of organic matter. Thus long-term usage 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 incineration of sludge. Sewage sludges contain trace elements at concentrations that, on a dry weight basis, often greatly exceed normal concentrations in productive soils. Many environmentalists are therefore concerned that heavy metals and metalloids may eventually accumulate and reach phytotoxic levels. Some are concerned that concentrations of certain trace elements may be enhanced in food and feed stuffs to such an extent that they may present a health hazard to man and animals.

Our research was directed toward providing data needed to evaluate threats to soil productivity, the environment in general and human health. The following is a brief statement of specific objectives which are expressed in more detail in appropriate sections of the report.

Objective 1.

Two field studies continued earlier investigations designed to monitor long-term accumulations of sludge-borne trace elements in soils and strip mine spoil material and determine their effect on corn yields and uptake by plants. Previous results were presented and discussed in two progress reports submitted to the Metropolitan Sanitary District of Greater Chicago and the U.S. Environmental Protection Agency (Hinesly et al., 1974; Hinesly and Hansen, 1981).

Objective 2.

Two other field studies were done to determine the residual effects of previous sludge applications on yields of corn, wheat, and soybeans and their trace element contents.

Objective 3.

One new field study was established to determine the effects of sewage sludge on plant growth, chemical composition of plant tissues, and changes in the chemical and physical properties of the spoil material when one-time applications of dewatered, digested sewage sludge were applied at rates far exceeding those required for maximum crop yields.

Objective 4.

Another field study was conducted to demonstrate that the uptake and accumulation of Cd and Zn in above-ground plant parts are consistently determined much more by the genetic constitution of plants than by the total concentrations of the metals in soils.

Objective 5.

Three greenhouse studies provided information about the effects of soil cation exchange capacity and Cd source on the uptake of Cd by corn and spinach.

Objective 6.

The report concludes with a discussion of the results from a long-term poultry feeding study. Three levels of Cd, biologically incorporated in soybean and corn diets, were fed to chicks and throughout their productive life as laying hens. Concentrations of Cd and other elements in various tissues were periodically determined from sacrificed birds, along with other measurements and observations for health effects.

SECTION 2

CONCLUSIONS

Where digested sludge was annually applied by furrow irrigation for 13 years on Blount silt loam, the growth and yields of two different corn hybrids indicated no imminent phytotoxic conditions. This observation held true even on plots receiving 10 times the sludge application rate that would supply recommended rates of supplementary nitrogen for corn. Corn yields were increased by sludge applications in 2 of the last 3 years of the study. During the last 3 years of the study, further sludge applications failed to increase soil contents of organic C, N, K, Na, Ca, Mg, Fe, and Mn, but they did increase Cd, Cu, Cr, Ni, P, Pb, and Zn at the 0- to 30-cm depth. Except for Cd and Zn, there was no indication that sludge constituents had leached below the 30-cm depth. But Cd and Zn concentrations were not increased in soil depths below 45 cm. Though nothing indicates that significant amounts of heavy and transition metals were lost from the soil profile by leaching, about 40% of the total amounts added as constituents of sludge either disappeared from the soil or were not detected by the core sampling method used in this study. Only Cd, Cu, Ni, and Zn were consistently higher in above-ground parts of plants grown on sludge-treated plots as compared with those on control plots. But these elements were not increased in plant tissues by accumulative applications of sludge-borne Cd, Cu, Ni, and Zn. For a particular loading rate and corn hybrid, contents of these heavy metals remained fairly constant after about 3 years of sludge application. There was no indication that a phytotoxic condition is likely to develop as a result of the repeated use of the Chicago sludge as a fertilizer.

Where the protocol for a sludge study on calcareous strip-mine spoil was the same as that on acid Blount silt loam, as discussed above, the results were similar. The one exception was that Cd and Zn concentrations in corn plant tissues increased as a result of accumulative sludge-borne applications of these metals. 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.

Where one-time applications of dewatered, digested sludge were made on level strip-mine spoil at rates of 0, 224, 448, and 896 mt/ha, plant growth and yields were increased by the two intermediate loading rates as compared with those on highly fertilized control plots. Organic C, N, P, and heavy metals were increased in the 0- to 18-cm depth of spoil in proportion to sludge loading rates. Spoil pH decreased, electrical conductivity of water extracts increased, the percent of water-stable aggregates increased, and the water-holding capacity of spoil increased in proportion to higher sludge loading rates. Two years after sludge applications were made, organic-C and N contents remained close to initial post application levels in spoil; but heavy metal contents had decreased in the spoil surface. Concentrations of Cd, Cu, and Pb were increased in spoil below the depth of mixing, but not below the 60-cm depth. Concentrations of Cd, Cu, Pb, Ni, and Zn in spoil below the depth of sludge mixing were too low to account for losses observed in the surface layer. Concentrations of Mg, P, Mn, Cd, Ni, and Zn were increased in corn, wheat, and rye grain by sludge applications during the first year. During the second year, Ni was not increased in grain by sludge applications, and Cd contents were considerably less. Doubling the 448-mt/ha sludge application did not increase grain Cd concentrations, but it did increase Zn concentrations. Above the intermediate sludge loading rate, it appeared that the availability of Cd for plant uptake was limited by other constituents contained in the sludge. Concentration ratios did not indicate that metal concentrations were increased as a result of low yields on maximum-sludge-treated plots, except for Ni. Results from this study suggest that in view of the low Cd content relative to concentrations of essential elements for animals (in particular Cu and Zn), 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 precaution will be required to protect ground water against contamination with NO_3-N where one-time, high-rate sludge applications are made.

On Blount silt loam plots irrigated annually for 5 years with digested sludge, corn yields began to decline 3 years after the last application. But applications of N fertilizer at recommended rates across all plots restored soil productivity to the original high level obtained with sludge applications. A year after sludge applications were terminated, organic C, total N, P, and heavy metal concentrations in Blount tended to remain rather constant. But the uptake of heavy metals by corn decreased each year and 4 years after sludge applications were terminated Cd and Zn concentrations in grain were no different from those in grain from control plots. 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 corn plants decrease with time and are not affected by applications of inorganic sources of N.

In other studies of the effects of residual sludge in soils, concentrations of Cd, Cu, Ni, and Zn were increased in soybean tissues by previous sludge applications. By order of listing, Ni, Cd, and Zn concentrations decreased most rapidly in soybean tissues after annual sludge applications were terminated. But 6 years after sludge applications were terminated, Cd and Zn concentrations in beans from plots previously treated with sludge were higher than those in beans from control plots. In a similar residual study using wheat, enhanced Ni and Cu concentrations in grain from plots previously treated with sludge returned to background levels in 3 years; but Cd and Zn uptake had not decreased 8 years after sludge applications had been suspended. Thus the decrease in availability of residual metal concentrations in soil from previous sludge applications varies with differences in crop species and probably with varieties within a particular species.

Results from a field study showed that two commercially available hybrids selected for their different capacities to take up Cd were indeed different when grown on split plots that had been irrigated annually with sludge during the 9 years before the 3-year study. Except in the first year of the study, grain Cd concentrations were less in the low-Cd hybrid grown on maximum-sludge-treated plots than they were in the high-Cd-accumulator grown on control plots. Cadmium 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. Thus enhancement of heavy metal concentrations in food and feed stuffs can be controlled by plant breeding.

The results from greenhouse studies showed that differences in soil cation exchange capacity (CEC) did not affect the uptake of sludge-borne Cd by corn, but CEC did substantially influence the uptake of Cd from soils amended with $CdCl_2$. Where soil CEC was due mainly to organic matter, less Cd was taken up by corn on $CdCl_2$-amended soil than on similarly amended soils where the CEC was due to inorganic materials. The uptake of Cd by spinach from soils amended with $CdCl_2$-spiked sludges was greater than when equivalent amounts of Cd were supplied as a natural constituent of digested sludge. Thus 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.

Corn hybrids and soybean cultivars were selected for different capacities to take up Cd and were grown in a sludge-amended field to obtain distinctly different levels of Cd concentrations in corn grain and beans. The corn grain and processed beans were formulated into starter, developer, and layer rations to provide three different levels of biologically incorporated Cd. In birds sacrificed at 8, 20, 50, 72, and 80 weeks, Cd concentrations in crop, proventriculus, muscular gizzard, gizzard lining, duodenum, liver, kidney, pancreas, and spleen tissues paralleled levels of the metal in diets. But Cd concentrations in leg muscle, breast muscle, and femur bone were unrelated to metal levels in the diets. For the tissues that accumulated Cd (except the kidneys), concentrations appeared to reach an equilibrium with Cd levels in the diet at about 50 weeks of age. In kidneys, Cd levels continued to increase regardless of dietary levels. Also, when birds were switched from high- to low-Cd diets, Cd concentrations decreased rather rapidly in all accumulator tissues but the kidneys. 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.

Since no evidence showed that the highest possible level of biologically incorporated Cd increased levels of the metal in egg shells, whites, or yolks, or in muscle tissues and bones, the probability of increasing Cd in human foods to harmful levels is nominal.

SECTION 3

RECOMMENDATIONS

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

1. Sewage sludges containing excessive concentrations of heavy metals and metalloids should be spread only on lands owned and operated by the wastewater treatment plant authority to ensure that site operation includes application methods, soil management practices, selection of appropriate crops, and crop disposal procedures that minimize potential contamination of water supplies and recycling of toxic concentrations of trace elements in food chains.

2. To protect ground water supplies from the leaching of NO_3-N, sludge loading rates should not exceed amount needed to meet nitrogen fertilizer recommendations.

3. Where excessive leaching of NO_3-N is prevented by the presence of slowly permeable geological material, one-time, high-rate sludge applications provide several advantages over annual low-rate applications when the object is to restore severely disturbed lands to a highly productive state. One-time, high-rate applications provide the opportunity to use various tillage, crop, and water management techniques that minimize water and wind erosion more than is possible when sludge is applied annually. Optimum sludge-loading rates for one-time applications in humid regions is about 200 mt/ha (dry weight).

4. Since most metals and metalloids contained in stabliized digested sewage sludges will not cause phytotoxic conditions in soils, the main concern is to protect food supplies against excessive concentrations of chemical elements accumulated by plants. Particular attention should be given to minimizing accumulations of Cd and Ni in plants. More attention should be given to selecting or producing crop varieties or cultivars by breeding that can severely limit metal uptake in plant parts used for food while maintaining adequate concentrations of other essential trace elements.

5. When plant materials containing enhanced Cd concentrations are fed to animals, only the muscle tissues should be consumed by humans.

6. When further research on sludge use is funded, priority should be given to determining how sludge-borne heavy metals are lost from soils.

SECTION 4

LONG-TERM FIELD STUDIES

RESPONSES OF CONTINUOUS CORN GROWN ON THREE SOIL TYPES PREVIOUSLY AMENDED WITH ANNUAL APPLICATIONS OF DIGESTED SEWAGE SLUDGE

Introduction

From a review of the most current data, members of a task group (CAST 1980) concluded that "the length of time sludge-derived Cd and Zn remain available to crops after sludge applications have ceased is indeterminate". They thought it likely that concentrations of these metals would increase in plant tissues if the soil pH was allowed to decrease.

The main objective of this study was to obtain information about the uptake of transition and heavy metals by one corn hybrid after suspending further annual applications of sewage sludge.

Methods and Materials

Forty-four lysimeter plots each 3.05 by 15.25 m in size were established in 1969 to measure the effects of various application rates of digested, municipal sewage sludge on soils, crops, surface water, and ground water. Three soil types were represented in the lysimeter plots. Plainfield sand, Elliott silt loam, and Blount silt loam were treated with three rates of sludge. About 25.4 mm of liquid sludge was applied on maximum-treated plots throughout the growing season as often as permitted by weather conditions. About 12.7 and 6.4 mm of sludge was applied on 1/2- and 1/4-maximum-treated plots, respectively, on the same day that maximum applications were made. Also on the same day, control plots were irrigated with 25.4 mm of well water. The lysimeters were divided into north and south groups of 22 plots each. The north lysimeters were used in this study. Prior to beginning this study, 232.5 mt/ha of solids, 8,044 kg P/ha, 58.3 kg Cd/ha, and 1290 kg Zn/ha had been applied on maximum-treated plots as constituents of sludge. After 5 years sludge applications were terminated on all plots except for maximum-treated Elliott silt loam and Plainfield sand. These plots received an extra 3-years of sludge applications and through 1976 sludge constituents amounted to 423 mt/ha a/solids, 14,875 kg P/ha, 112.7 kg Cd/ha, and 2,169 kg Zn/ha.

Details of this study were described in previous publications (Hinesly et al, 1979; Hinesly and Hansen, 1981). The same corn hybrid (Pioneer 3517) was planted during years when soils were irrigated with digested sewage sludge and after applications were suspended. During the last 2 years, 179 kg/ha of N was broadcast on the entire plot area each spring before plots were tilled.

Results and Discussion

The persistence of changes in several soil properties caused by sludge applications can be seen in Table 1. Organic-C and N contents in the 0 to 15 cm depth of Blount continued to be significantly higher in sludge-treated plots and had changed very little since sludge applications were suspended. After sludge applications were terminated on maximum-treated Elliott and Plainfield, organic-C and N contents remained fairly stable. These data indicate that after the initial flush of mineralization that occurred during the first year after sludge organic matter was incorporated into soils, the remaining material was highly resistant to further degradation. The rate of degradation was affected very little by differences in soil type.

Concentrations of K, Na, Ca, Mg, Fe, and Mn in soils were unaffected by sludge applications (Table 1). Concentrations of P, Cd, Cu, Cr, Ni, Pb, and Zn were significantly increased in the 0 to 15 cm depth of Blount by sludge applications. Where sludge was applied for an additional 3 years on maximum-treated Elliott and Plainfield, concentrations of Cu, Cr, Ni, and Pb were increased throughout the 0 to 30 cm soil depths. Zinc concentrations in these two soils were increased to depths of 46 cm. Cadmium concentrations were also increased to depths of 46 cm in Plainfield, and concentrations of this metal increased in the 61 to 76 cm depth of maximum-treated Elliott plots. Thus, the chemical composition of Blount was changed only in the plow layer depth by 5 years of repeated sludge applications, but an additional 3 years of applications on maximum-treated Elliott and Plainfield resulted in migration of these chemical elements to deeper soil depths. Although a great deal of year to year variability in concentration of transition and heavy metals in soils existed, probably as a result of the inadequate number of soil cores collected each year, there is no evidence of an extensive loss of any chemical element from the soil surface after sludge applications were terminated. During the last 3 years of the study, it was evident that maximum sludge applications had decreased soil pH in all soil types to a depth of 30 cm.

Residual effects of sludge applications on Blount produced an increase in corn yields during 1976, 1977, and 1978. But after N fertilizer was applied in 1979, yields were not significantly different, regardless of treatment (Table 2). During the three years after sludge applications were discontinued, corn yields tended to decline each year until N fertilizer was applied across all plots. After N was applied, yields for the last 2 years on Blount were as high as average yields during the 10-year corn study. Corn was first planted on the north series of lysimeter plots in 1971. Stover yields on Blount were similar to grain yields and there were no indications that residual effects from sludge adversely affected the soil productivity. In the last year of the study, grain yields from Elliott silt loam were unusually low where maximum amounts of sludge were formerly applied, but Stover yields from the plot were among the higher ones recorded during the study. Grain and Stover yields from Plainfield loamy sand were

TABLE 1. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS AND SOIL pH IN BLOUNT SILT LOAM, ELLIOTT SILT LOAM AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS LOCATED IN A NORTH SERIES.[a/]

			Soil Type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Ana-lyte	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Org-C															
	0-15	1978	0.88	1.23	1.31	1.60	n.s.	1.54	1.55	1.72	3.77	0.42	0.34	0.89	3.35
		1979	0.73	1.09	1.54	1.54	0.39**	1.51	1.68	1.19	2.60	0.49	0.47	0.81	2.10
		1980	1.00	1.32	1.62	1.84	0.47**	1.62	1.89	1.87	3.20	0.64	0.83	0.52	3.03
	15-30	1978	0.80	0.60	0.63	0.77	n.s.	1.25	1.60	1.43	1.83	0.22	0.29	0.59	0.40
		1979	0.76	0.62	0.62	0.61	n.s.	1.04	1.63	1.40	1.36	0.30	0.17	0.44	0.46
		1980	0.85	0.72	0.55	0.70	n.s.	1.38	1.63	1.37	1.29	0.19	0.23	0.20	0.37
	30-46	1978	0.59	0.48	0.50	0.47	n.s.	0.44	0.94	0.95	0.90	0.06	0.05	0.10	0.09
		1979	0.49	0.44	0.42	0.49	n.s.	0.34	0.66	0.48	0.59	0.04	0.12	0.09	0.01
	61-76	1978	0.33	0.41	0.33	0.41	n.s.	0.30	0.38	0.44	0.45	0.04	0.05	0.01	0.11
		1979	0.46	0.47	0.38	0.41	n.s.	0.34	0.60	0.41	0.38	0.08	0.11	0.04	0.13

(continued)

TABLE 1. (continued)

Analyte	Depth cm	Year	Soil Type: Blount silt loam Ck	1/4 Max	1/2 Max	Max	LSD	Elliott silt loam Ck	1/4 Max	1/2 Max	Max	Plainfield loamy sand Ck	1/4 Max	1/2 Max	Max
			%												
N	0-15	1978	0.100	0.119	0.152	0.179	0.018**	0.147	0.150	0.172	0.350	0.041	0.055	0.057	0.342
		1979	0.103	0.113	0.133	0.140	0.023*	0.140	0.120	0.170	0.250	0.055	0.080	0.090	0.210
		1980	0.101	0.119	0.141	0.156	0.029*	0.129	0.164	0.164	0.291	0.057	0.069	0.076	0.234
	15-30	1978	0.082	0.077	0.078	0.086	n.s.	0.121	0.153	0.132	0.164	0.028	0.034	0.054	0.045
		1979	0.087	0.070	0.070	0.070	n.s.	0.100	0.150	0.130	0.130	0.030	0.020	0.050	0.050
		1980	0.091	0.094	0.071	0.080	n.s.	0.073	0.146	0.123	0.127	0.016	0.049	0.022	0.042
	30-46	1978	0.079	0.069	0.062	0.061	n.s.	0.053	0.101	0.097	0.089	0.014	0.010	0.015	0.021
		1979	0.067	0.070	0.050	0.063	n.s.	0.065	0.080	0.080	0.070	0.010	0.010	0.020	0.010
	61-76	1978	0.057	0.070	0.064	0.072	n.s.	0.050	0.068	0.061	0.072	0.022	0.010	0.006	0.013
		1979	0.053	0.060	0.050	0.053	n.s.	0.045	0.060	0.050	0.050	0.010	0.010	0.010	0.010

(continued)

TABLE 1. (continued)

Analyte	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	Blount silt loam LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			%												
P	0-15	1978	0.078	0.111	0.152	0.217	0.023**	0.073	0.100	0.155	0.417	0.044	0.077	0.112	0.496
		1979	0.072	0.101	0.123	0.152	0.044**	0.067	0.098	0.133	0.258	0.056	0.105	0.133	0.308
		1980	0.070	0.113	0.152	0.193	0.057**	0.080	0.110	0.114	0.327	0.059	0.084	0.086	0.416
	15-30	1978	0.041	0.064	0.039	0.050	n.s.	0.044	0.052	0.051	0.101	0.039	0.050	0.100	0.082
		1979	0.044	0.066	0.043	0.044	n.s.	0.046	0.063	0.054	0.092	0.041	0.041	0.081	0.093
		1980	0.049	0.070	0.040	0.058	n.s.	0.050	0.052	0.054	0.059	0.038	0.041	0.049	0.077
	30-46	1978	0.037	0.049	0.037	0.041	n.s.	0.041	0.057	0.043	0.068	0.027	0.022	0.032	0.024
		1979	0.031	0.036	0.029	0.032	n.s.	0.034	0.034	0.025	0.036	0.024	0.021	0.032	0.028
	61-76	1978	0.041	0.043	0.040	0.041	n.s.	0.043	0.044	0.042	0.061	0.020	0.024	0.019	0.039
		1979	0.033	0.031	0.037	0.035	n.s.	0.031	0.036	0.031	0.033	0.020	0.016	0.015	0.020

(continued)

TABLE 1. (continued)

Analyte	Depth cm	Year	Soil Type: Blount silt loam Ck	1/4 Max	1/2 Max	Max	LSD	Elliott silt loam Ck	1/4 Max	1/2 Max	Max	Plainfield loamy sand Ck	1/4 Max	1/2 Max	Max
			%												
K	0-15	1978	2.03	2.17	2.12	2.09	n.s.	1.99	2.06	2.08	1.94	1.50	1.60	1.45	1.63
		1979	2.07	2.21	2.08	2.12	n.s.	2.04	2.04	2.00	1.98	1.64	1.69	1.42	1.56
		1980	2.01	2.08	2.13	2.00	n.s.	1.97	1.93	1.60	2.06	1.74	1.71	1.27	1.56
	15-30	1978	2.06	2.13	2.09	1.99	n.s.	1.99	1.95	2.01	2.00	1.55	1.59	1.49	1.46
		1979	2.08	2.19	2.06	1.73	n.s.	1.97	2.02	2.05	2.03	1.47	1.29	1.30	1.20
		1980	1.98	2.13	2.03	1.94	n.s.	1.94	1.91	1.99	1.97	1.42	1.46	1.45	1.46
	30-46	1978	1.89	2.26	2.05	1.88	n.s.	1.99	1.99	2.11	1.36	1.33	1.28	1.68	1.11
		1979	2.04	2.56	2.27	1.95	n.s.	2.39	2.12	2.11	2.08	1.31	1.27	1.31	1.47
	61-76	1978	1.97	2.34	2.46	2.43	n.s.	2.55	2.44	2.42	2.01	1.13	1.63	1.24	1.44
		1979	2.06	2.74	2.39	2.48	n.s.	2.57	2.37	2.48	2.04	1.33	1.22	1.08	1.26

(continued)

TABLE 1. (continued)

Analyte	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	Blount silt loam LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			%												
Na	0-15	1978	0.668	0.671	0.704	0.690	n.s.	0.748	0.735	0.708	0.655	0.635	0.667	0.618	0.637
		1979	0.749	0.775	0.809	0.784	n.s.	0.800	0.795	0.740	0.755	0.748	0.700	0.630	0.638
		1980	0.706	0.664	0.758	0.689	n.s.	0.740	0.748	0.574	0.681	0.713	0.678	0.585	0.635
	15-30	1978	0.709	0.601	0.701	0.724	n.s.	0.696	0.722	0.700	0.655	0.646	0.644	0.633	0.644
		1979	0.722	0.616	0.676	0.702	n.s.	0.638	0.708	0.678	0.649	0.613	0.536	0.527	0.462
		1980	0.797	0.709	0.704	0.721	n.s.	0.748	0.752	0.712	0.740	0.683	0.703	0.712	0.689
	30-46	1978	0.619	0.468	0.483	0.553	n.s.	0.513	0.641	0.618	0.677	0.651	0.610	0.604	0.503
		1979	0.694	0.493	0.549	0.610	n.s.	0.492	0.606	0.481	0.668	0.581	0.568	0.591	0.591
	61-76	1978	0.651	0.514	0.517	0.481	n.s.	0.528	0.562	0.416	0.691	0.545	0.783	0.599	0.698
		1979	0.640	0.430	0.561	0.576	n.s.	0.516	0.535	0.423	0.644	0.565	0.555	0.520	0.537

(continued)

TABLE 1. (continued)

Ana-lyte	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			%												
Ca	0-15	1978	1.37	1.37	1.26	1.54	n.s.	0.72	0.88	1.11	0.90	0.55	0.72	0.56	0.93
		1979	1.06	1.24	0.85	1.26	n.s.	0.68	0.68	0.84	0.66	0.54	0.64	0.44	0.59
		1980	1.28	1.11	0.98	1.17	n.s.	0.82	0.71	0.77	0.80	0.65	0.71	0.47	0.71
	15-30	1978	1.19	1.21	0.64	0.84	n.s.	1.03	0.69	0.91	1.31	0.62	0.90	0.77	0.51
		1979	0.83	0.64	0.46	0.66	n.s.	1.10	0.52	1.05	1.45	0.52	0.38	0.45	0.38
		1980	0.62	0.58	0.34	0.41	n.s.	0.69	0.50	0.69	0.46	0.40	0.51	0.42	0.35
	30-46	1978	0.71	0.80	0.37	0.78	n.s.	1.07	0.85	1.37	2.09	0.40	0.44	0.47	0.30
		1979	0.34	0.31	0.45	0.67	n.s.	0.37	0.40	1.18	1.24	0.25	0.37	0.37	0.32
	61-76	1978	0.97	1.40	1.28	0.90	n.s.	0.92	0.57	2.20	0.60	0.30	0.35	0.37	0.41
		1979	0.77	0.98	0.86	0.84	n.s.	2.22	0.82	2.09	0.40	0.22	0.26	0.24	0.30

(continued)

TABLE 1. (continued)

			Soil Type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Ana-lyte	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Mg	0-15	1978	0.894	0.915	0.833	0.949	n.s.	0.589	0.711	0.785	0.680	0.359	0.449	0.304	0.534
		1979	0.750	0.877	0.606	0.786	n.s.	0.532	0.518	0.595	0.545	0.341	0.396	0.246	0.336
		1980	0.647	0.647	0.645	0.712	n.s.	0.608	0.690	0.608	0.571	0.458	0.520	0.367	0.391
	15-30	1978	0.765	0.802	0.660	0.671	n.s.	0.735	0.555	0.709	0.884	0.341	0.404	0.339	0.252
		1979	0.565	0.598	0.490	0.500	n.s.	0.706	0.418	0.737	0.901	0.249	0.167	0.179	0.149
		1980	0.527	0.557	0.506	0.510	n.s.	0.574	0.442	0.623	0.679	0.234	0.283	0.213	0.201
	30-46	1978	0.627	0.783	0.557	0.748	n.s.	0.692	0.710	1.10	1.28	0.195	0.192	0.167	0.148
		1979	0.527	0.721	0.750	0.782	n.s.	0.690	0.628	1.17	0.984	0.135	0.128	0.153	0.153
	61-76	1978	0.926	1.08	1.19	0.982	n.s.	0.91	0.89	1.09	0.770	0.133	0.162	0.156	0.238
		1979	0.727	1.04	0.876	0.796	n.s.	0.966	0.842	1.01	0.663	0.122	0.119	0.095	0.119

(continued)

TABLE 1. (continued)

Analyte	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	Blount silt loam LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			%												
Fe	0-15	1978	2.37	2.56	2.49	2.38	n.s.	2.22	2.54	2.60	2.87	1.05	1.19	1.14	1.96
		1979	2.51	2.49	2.07	2.38	0.29*	2.22	2.56	2.51	2.76	1.37	1.51	1.32	1.60
		1980	2.72	2.55	2.28	2.24	n.s.	2.30	2.43	2.17	2.63	1.59	1.66	1.10	1.87
	15-30	1978	3.11	3.56	3.23	2.69	n.s.	3.23	3.01	3.24	3.67	1.39	1.49	1.34	1.15
		1979	2.55	3.32	2.66	2.26	n.s.	2.68	2.60	2.65	2.91	1.14	0.63	0.81	0.63
		1980	2.91	3.05	2.69	2.88	n.s.	2.81	2.50	2.92	3.08	1.05	1.42	1.47	1.14
	30-46	1978	2.82	4.18	3.46	3.12	n.s.	3.64	2.71	3.03	1.90	0.78	0.55	1.27	0.60
		1979	2.99	5.74	4.10	3.51	1.66*	3.97	4.27	3.88	3.19	0.66	0.77	0.76	0.94
	61-76	1978	4.49	4.69	4.76	5.32	n.s.	4.66	7.33	4.34	4.34	0.56	1.06	0.80	1.28
		1979	4.59	4.20	4.03	4.25	n.s.	4.80	5.97	3.90	4.18	0.66	0.66	0.57	0.66

(continued)

TABLE 1. (continued)

Analyte	Depth cm	Year	Soil Type: Blount silt loam Ck	Blount 1/4 Max	Blount 1/2 Max	Blount Max	LSD	Elliott silt loam Ck	Elliott 1/4 Max	Elliott 1/2 Max	Elliott Max	Plainfield loamy sand Ck	Plainfield 1/4 Max	Plainfield 1/2 Max	Plainfield Max
			mg/kg												
Mn	0-15	1978	847	791	924	887	n.s.	1010	1100	787	912	323	357	278	447
		1979	833	752	827	848	n.s.	796	833	729	818	349	329	243	308
		1980	898	839	1000	860	n.s.	868	958	661	728	502	402	237	410
	15-30	1978	921	716	791	876	n.s.	835	926	812	1243	297	301	255	235
		1979	889	682	681	749	n.s.	709	904	759	898	320	190	209	184
		1980	1020	787	732	842	n.s.	886	951	930	1080	308	271	283	277
	30-46	1978	760	615	577	594	n.s.	633	869	751	860	246	183	228	183
		1979	698	857	502	481	n.s.	586	781	447	781	167	151	158	183
	61-76	1978	747	627	723	670	n.s.	718	828	749	495	137	150	150	265
		1979	688	661	686	778	n.s.	678	854	637	618	153	146	97	159

(continued)

TABLE 1. (continued)

Analyte	Depth cm	Year	Blount silt loam Ck	Blount 1/4 Max	Blount 1/2 Max	Blount Max	Blount LSD	Elliott silt loam Ck	Elliott 1/4 Max	Elliott 1/2 Max	Elliott Max	Plainfield loamy sand Ck	Plainfield 1/4 Max	Plainfield 1/2 Max	Plainfield Max
			mg/kg												
Zn	0-15	1978	81	180	267	379	37**	79	187	263	673	35	137	199	804
		1979	89	134	178	236	67**	80	144	196	428	51	143	203	442
		1980	87	159	240	313	85**	84	187	184	551	58	129	139	639
	15-30	1978	75	82	74	74	n.s.	67	77	75	200	24	64	159	145
		1979	83	89	83	67	n.s.	78	94	83	190	37	37	103	118
		1980	76	85	73	91	n.s.	76	83	90	114	30	52	69	129
	30-46	1978	90	109	96	84	n.s.	76	84	84	142	18	15	26	30
		1979	74	111	90	83	n.s.	86	99	89	110	19	19	42	28
	61-76	1978	92	97	105	108	n.s.	92	158	82	125	21	12	13	22
		1979	96	108	96	104	n.s.	93	154	93	102	18	17	18	24

(continued)

TABLE 1. (continued)

Ana-lyte	Depth cm	Year	Soil Type: Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	Blount silt loam LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			mg/kg												
Cd	0-15	1978	0.62	4.65	9.41	13.5	1.37**	0.65	4.84	8.96	33.5	0.53	3.97	7.15	41.4
		1979	0.82	2.84	5.40	7.92	3.00**	0.76	2.86	6.36	18.4	0.64	4.69	7.53	22.7
		1980	0.54	3.95	7.86	11.5	2.90**	0.69	5.15	6.18	25.3	0.87	4.20	5.29	32.2
	15-30	1978	<0.25	<0.25	<0.25	0.31	n.s.	<0.25	0.52	<0.25	5.16	<0.25	1.69	6.06	5.32
		1979	0.30	<0.25	0.43	0.50	n.s.	<0.25	0.82	0.53	4.53	0.34	1.13	3.78	4.83
		1980	<0.25	<0.25	<0.25	0.54	n.s.	<0.25	<0.25	0.47	1.18	<0.25	1.17	2.05	4.36
	30-46	1978	<0.25	<0.25	0.32	<0.25	n.s.	<0.25	0.40	<0.25	3.22	<0.25	0.37	0.49	0.62
		1979	<0.25	<0.25	<0.25	0.30	n.s.	0.30	0.31	<0.25	1.54	<0.25	<0.25	1.18	0.45
	61-76	1978	<0.25	0.36	<0.25	<0.25	n.s.	<0.25	0.28	<0.25	1.48	<0.25	<0.25	<0.25	<0.25
		1979	<0.25	<0.25	<0.25	0.32	n.s.	<0.25	0.34	0.39	0.52	<0.25	<0.25	<0.25	<0.25

(continued)

TABLE 1. (continued)

Analyte	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	Blount silt loam LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			mg/kg												
Cu	0-15	1978	26	44	68	94	8**	26	44	68	214	12	33	50	245
		1979	22	36	48	62	20**	19	36	50	125	12	36	52	150
		1980	28	45	67	86	20**	26	51	54	184	21	37	36	224
	15-30	1978	18	31	23	21	n.s.	19	21	19	49	7	14	36	49
		1979	19	25	22	19	n.s.	19	26	23	54	9	19	31	42
		1980	23	26	22	27	n.s.	22	21	26	29	9	15	23	38
	30-46	1978	25	36	33	29	n.s.	29	27	30	45	6	14	9	11
		1979	22	36	29	25	n.s.	29	30	30	31	6	7	10	6
	61-76	1978	24	32	36	34	n.s.	32	53	25	36	9	76	19	4
		1979	36	41	37	42	n.s.	35	48	40	42	10	16	47	10

(continued)

TABLE 1. (continued)

Analyte	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	Blount silt loam LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			mg/kg												
Ni	0-15	1978	30	32	35	40	7**	29	30	36	75	14	18	17	73
		1979	26	27	27	28	n.s.	28	23	27	51	16	19	17	39
		1980	36	38	39	43	4*	31	36	41	68	20	24	17	63
	15-30	1978	21	25	18	19	n.s.	18	15	17	30	11	18	14	16
		1979	22	24	19	18	n.s.	21	19	23	32	14	7	14	14
		1980	29	31	24	26	n.s.	24	24	26	40	13	16	15	20
	30-46	1978	22	35	29	22	9*	29	22	34	30	9	8	13	8
		1979	24	38	31	27	n.s.	33	29	40	30	9	7	11	10
	61-76	1978	33	37	40	42	n.s.	39	48	37	27	3	6	5	11
		1979	32	48	43	40	n.s.	41	39	44	31	9	9	9	9

(continued)

TABLE 1. (continued)

			Soil Type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Ana-lyte	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			mg/kg												
Cr	0-15	1978	54	95	145	207	30**	50	90	155	432	29	55	90	522
		1979	59	89	104	126	36**	60	81	110	193	38	85	105	234
		1980	40	63	87	121	26**	37	71	91	220	25	52	39	352
	15-30	1978	47	51	48	44	n.s.	45	46	48	94	24	43	83	61
		1979	39	43	40	41	n.s.	45	42	48	87	26	22	55	65
		1980	40	45	44	48	n.s.	36	39	36	38	17	27	24	49
	30-46	1978	44	62	62	49	n.s.	51	43	70	70	10	15	12	7
		1979	40	56	52	52	n.s.	52	46	59	60	9	8	18	19
	61-76	1978	54	63	59	55	n.s.	58	54	61	69	14	14	13	20
		1979	41	54	56	48	n.s.	57	46	64	40	8	3	3	6

(continued)

TABLE 1. (continued)

Analyte	Depth cm	Year	Blount silt loam Ck	Blount 1/4 Max	Blount 1/2 Max	Blount Max	Blount LSD	Elliott silt loam Ck	Elliott 1/4 Max	Elliott 1/2 Max	Elliott Max	Plainfield loamy sand Ck	Plainfield 1/4 Max	Plainfield 1/2 Max	Plainfield Max
			mg/kg												
Pb	0-15	1978	26	38	58	78	9**	25	37	56	158	13	31	48	177
		1979	27	38	51	61	16**	23	41	53	104	17	40	51	124
		1980	34	47	67	81	21**	28	51	48	145	30	36	37	158
	15-30	1978	19	18	19	20	n.s.	19	21	23	41	9	24	36	27
		1979	23	21	19	18	n.s.	19	27	22	36	11	18	31	30
		1980	28	24	18	24	6*	20	20	24	38	10	14	39	26
	30-46	1978	19	21	18	17	n.s.	18	21	18	28	7	7	8	7
		1979	21	28	23	22	n.s.	22	26	22	25	7	7	11	12
	61-76	1978	21	21	21	22	n.s.	19	32	18	31	7	11	5	10
		1979	23	24	20	23	n.s.	20	30	20	22	6	6	6	6

(continued)

TABLE 1. (continued)

			Soil Type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Analyte	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			units												
pH	0-15	1978	7.5	7.6	7.3	7.1	0.3*	7.2	7.2	7.4	5.8	7.4	7.7	7.0	5.9
		1979	7.6	7.5	7.1	7.1	n.s.	7.0	7.0	7.2	6.1	7.4	7.4	7.1	6.2
		1980	7.4	7.3	7.1	7.0	0.2*	7.0	7.1	7.2	6.1	7.3	7.4	7.1	6.1
	15-30	1978	6.9	6.9	6.1	6.2	n.s.	7.4	6.9	6.9	6.4	7.3	7.6	7.1	6.0
		1979	6.9	6.7	5.9	6.0	n.s.	7.4	6.7	7.2	7.1	7.3	7.6	7.5	7.4
		1980	6.8	6.9	5.5	5.9	1.1**	7.3	6.7	7.0	6.8	7.5	7.2	7.4	6.3
	30-46	1978	6.4	6.5	5.4	5.8	n.s.	6.8	6.7	6.7	7.0	7.0	7.5	6.8	5.8
		1979	6.2	5.5	5.6	5.6	n.s.	6.2	6.9	6.9	5.3	7.2	7.3	6.8	6.5
	61-76	1978	5.9	7.0	6.7	5.7	n.s.	6.9	6.2	7.3	4.9	6.8	6.8	6.6	6.5
		1979	5.8	7.2	6.7	6.3	n.s.	7.6	6.6	7.7	5.0	7.2	7.4	6.7	7.1

a/ Blount silt loam control and sludge-treated plots were replicated three times. Sludge treatments on other soil types were not replicated within a series.
*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

low and highly variable as expected. Because Plainfield is so droughty, corn is seldom grown on it in Illinois. Sludge did not improve the productivity of the sandy soil beyond its fertilizer value. Furthermore, there was no indication that sludge improved yields from Plainfield compared to those obtained with inorganic commercial fertilizers.

Other than effects on Mn, Cd, and Zn concentrations, there were no obvious changes in plant composition attributable to previous applications of sludge (Table 3). Residual effects of sludge applications were manifested by lower leaf- and grain-Mn; higher leaf-, grain- and Stover- Zn; and higher leaf-and Stover-Cd concentrations with higher sludge loading rates. Where plots had not received sludge for 4 years, since 1973, concentrations of Cd in grain were not significantly different than those in grain from control plots, regardless of soil type. It is noteworthy that even though Plainfield had a very low (3 to 4 meq/100 g) and Elliott a rather high (14 to 15 meq/100 g) cation exchange capacity, Cd and Zn contents in corn tissues were not significantly different. This observation was even more phenomenal in view of the 2-fold or higher yields of grain and stover from Elliott plots. These data suggest that the diluting effect generally expected as a result of better growth did not occur where the metals were supplied as constituents of sludge.

Four years after sludge applications were terminated on maximum-treated Blount plots, concentrations of Cd and Zn in grain from these plots were not different from those in grain from control plots. But 4 years after sludge applications were terminated on maximum-treated Elliott and Plainfield, levels of Cd and Zn in grain were significantly higher than those in grain from control plots even though a substantial reduction in concentrations had occurred. At the time sludge applications were terminated, maximum-treated Blount contained 12.3 ± 3.6 and 327 ± 9.3 mg/kg of Cd and Zn, whereas, when maximum sludge applications were terminated on Elliott and Plainfield, they contained 26 ± 7.5 and 32 ± 9.3 mg/kg of Cd, respectively, in their surface layers. Concentrations of Zn in these two sludge-treated soil types were 409 ± 17.3 and 623 ± 181, respectively. Thus, it appears that where higher amounts of sludge borne Cd and Zn accumulated in soils, a longer period without further sludge applications will be required to reduce uptake of these metals to background levels by the particular hybrid used in the study.

Summary and Conclusions

The results of this study showed that organic matter accumulated in soils by sludge application remained at fairly stable contents after the first year following the termination of applications. It nevertheless provided adequate amounts of N for acceptable corn yields for 3 years beyond the last year sludge was applied.

After sludge applications were terminated, Cd and Zn concentrations in corn plant tissues decreased with time. Relatively speaking, concentrations of Cd in corn grain decreased with time more rapidly than did those of Zn. The length of time after terminating sludge applications required for Cd and Zn to reach background levels of these metals in crop tissues depends on total amounts of sludge-borne metals accumulated in soils. The length

TABLE 2. CORN GRAIN AND STOVER YIELDS FROM LYSIMETER PLOTS OF THREE SOIL TYPES, WITH AND WITHOUT SEWAGE SLUDGE IRRIGATIONS. ALL THREE TYPES WERE REPRESENTED IN A NORTH SERIES.

	Soil Type												
	Blount silt loam [a]					Elliott silt loam [b]				Plainfield loamy sand [b]			
Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
	Grain Yields												
	mt/ha (15.5% moisture)												
1978	2.81	3.24	4.18	5.71	1.69**	2.81	3.40	2.45	3.99	0.494	0.753	1.24	0.565
1979	7.96	8.73	9.22	9.40	n.s.	8.03	9.40	9.53	7.51	4.44	3.25	3.60	2.92
1980	6.74	6.67	6.29	7.02	n.s.	5.22	4.37	4.63	2.70	2.54	1.82	2.24	1.04
	Stover Yields												
	mt/ha (dry weight)												
1978	4.20	4.76	6.55	5.43	1.44*	5.00	6.28	4.78	5,35	1.06	1.52	2.12	6.48
1979	7.69	8.14	9.11	9.53	n.s.	8.86	9.42	10.4	10.7	4.07	4.03	4.18	4.79
1980	6.65	6.80	7.16	7.73	n.s.	7.35	9.70	8.92	9.68	3.28	2.76	5.03	3.58

[a]-/Sludge application stopped after 1973.
[b]-/Sludge application stopped after 1973 except on Elliott and Plainfield maximum sludge plots applications continued through 1976.

TABLE 3. CONCENTRATIONS OF MACRO- AND MINOR- ELEMENTS IN CORN LEAF, GRAIN, STOVER GROWN ON BLOUNT SILT LOAM, ELLIOTT SILT LOAM, AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS, WITH AND WITHOUT DIGESTED SLUDGE IRRIGATIONS.a/b/

		Soil Type												
		Blount silt loam					Elliott silt loam				Plainfield loamy sand			
parameter	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
		%												
		Leaf												
N	1978	1.76	1.80	1.91	2.20	0.30**	1.96	1.73	1.66	3.31	1.36	1.38	1.59	2.38
	1979	2.78	2.53	2.50	2.67	n.s.	2.83	2.75	2.37	2.82	2.16	2.35	2.72	3.04
	1980	2.53	2.56	2:26	2.58	n.s.	2.54	2.48	2.39	2.91	2.22	2.41	2.02	2.35
		Stover												
	1978	0.39	0.34	0.35	0.37	n.s.	0.52	0.40	0.52	1.18	0.64	0.33	0.48	1.12
	1979	0.67	0.59	0.56	0.71	n.s.	0.81	0.61	0.61	1.05	0.71	0.79	0.85	1.42
	1980	0.80	0.87	0.88	0.95	n.s.	0.79	0.80	1.38	1.53	0.69	0.60	0.82	1.40
		Grain												
	1978	0.90	1.02	1.14	1.26	0.24*	1.27	1.02	1.12	1.86	1.34	1.43	1.30	1.73
	1979	1.49	1.49	1.54	1.59	n.s.	1.44	1.59	1.72	1.73	1.54	1.80	1.71	1.81
	1980	1.50	1.69	1.55	1.56	n.s.	1.58	1.82	1.73	2.25	1.42	1.75	1.84	1.31

(continued)

TABLE 3. (continued)

		Soil Type												
		Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
		%												
							Leaf							
P	1978	0.315	0.285	0.226	0.238	0.032**	0.252	0.278	0.239	0.351	0.385	0.374	0.335	0.389
	1979	0.277	0.256	0.243	0.252	n.s.	0.281	0.262	0.250	0.308	0.300	0.308	0.282	0.347
	1980	0.264	0.263	0.270	0.267	n.s.	0.310	0.278	0.300	0.333	0.325	0.298	0.255	0.288
							Stover							
	1978	0.163	0.127	0.117	0.071	n.s.	0.146	0.186	0.230	0.224	0.375	0.351	0.351	0.364
	1979	0.090	0.084	0.067	0.092	0.014*	0.108	0.087	0.111	0.140	0.134	0.117	0.063	0.245
	1980	0.063	0.056	0.050	0.073	n.s.	0.058	0.110	0.125	0.171	0.125	0.039	0.066	0.079
							Grain							
	1978	0.312	0.303	0.286	0.283	n.s.	0.302	0.280	0.324	0.369	0.354	0.347	0.375	0.371
	1979	0.338	0.303	0.263	0.280	0.043*	0.358	0.300	0.299	0.285	0.316	0.366	0.274	0.288
	1980	0.315	0.330	0.349	0.339	0.024*	0.344	0.352	0.384	0.346	0.342	0.369	0.361	0.370

(continued)

TABLE 3. (continued)

Parameter	Year	Soil Type: Blount silt loam Ck	1/4 Max	1/2 Max	Max	LSD	Elliott silt loam Ck	1/4 Max	1/2 Max	Max	Plainfield loamy sand Ck	1/4 Max	1/2 Max	Max
		Leaf												
		---% ---												
Ca	1978	0.593	0.685	0.751	0.739	n.s.	0.581	0.618	0.737	0.618	0.567	0.589	0.690	0.687
	1979	0.770	0.794	0.800	0.760	n.s.	0.756	0.767	0.829	0.773	0.643	0.610	0.644	0.864
	1980	0.681	0.730	0.687	0.674	n.s.	0.586	0.666	0.720	0.669	0.534	0.571	0.614	0.612
		Stover												
		---% ---												
	1978	0.427	0.425	0.409	0.470	n.s.	0.355	0.369	0.336	0.538	0.394	0.394	0.358	0.350
	1979	0.488	0.489	0.507	0.463	n.s.	0.426	0.388	0.473	0.438	0.466	0.465	0.510	0.507
	1980	0.314	0.335	0.279	0.234	n.s.	0.280	0.204	0.264	0.256	0.224	0.243	0.337	0.238
		Grain												
		---mg/kg---												
	1978	61	45	48	42	n.s.	56	64	44	45	57	52	50	35
	1979	52	60	54	62	n.s.	52	63	48	39	39	57	42	45
	1980	54	51	48	57	n.s.	37	51	60	42	46	42	51	60

(continued)

TABLE 3. (continued)

Parameter	Year	Blount silt loam Ck	Blount 1/4 Max	Blount 1/2 Max	Blount Max	LSD	Elliott silt loam Ck	Elliott 1/4 Max	Elliott 1/2 Max	Elliott Max	Plainfield loamy sand Ck	Plainfield 1/4 Max	Plainfield 1/2 Max	Plainfield Max
		%												
		Leaf												
Mg	1978	0.288	0.308	0.307	0.266	n.s.	0.286	0.296	0.185	0.225	0.387	0.364	0.371	0.302
	1979	0.338	0.336	0.347	0.315	n.s.	0.359	0.361	0.342	0.316	0.368	0.398	0.388	0.210
	1980	0.380	0.380	0.378	0.343	n.s.	0.368	0.400	0.380	0.286	0.324	0.319	0.357	0.330
		Stover												
	1978	0.263	0.251	0.239	0.269	n.s.	0.254	0.252	0.275	0.283	0.330	0.307	0.275	0.241
	1979	0.242	0.227	0.225	0.224	n.s.	0.224	0.209	0.244	0.222	0.290	0.279	0.306	0.339
	1980	0.186	0.183	0.189	0.143	n.s.	0.167	0.153	0.197	0.158	0.157	0.153	0.227	0.168
		Grain												
	1978	0.117	0.116	0.119	0.119	n.s.	0.124	0.111	0.128	0.138	0.137	0.131	0.145	0.153
	1979	0.189	0.115	0.107	0.150	n.s.	0.147	0.122	0.120	0.108	0.127	0.170	0.120	0.130
	1980	0.140	0.141	0.151	0.147	n.s.	0.144	0.147	0.166	0.147	0.147	0.167	0.152	0.160

(continued)

TABLE 3. (continued)

Parameter	Year	Soil Type: Blount silt loam Ck	1/4 Max	1/2 Max	Max	LSD	Elliott silt loam Ck	1/4 Max	1/2 Max	Max	Plainfield loamy sand Ck	1/4 Max	1/2 Max	Max
		mg/kg												
		Leaf												
Fe	1978	94	91	104	100	n.s.	91	85	73	103	97	96	100	96
	1979	135	116	97	115	n.s.	114	124	98	116	118	116	116	102
	1980	107	96	107	94	n.s.	109	100	109	104	102	87	92	104
		Stover												
	1978	227	202	239	139	n.s.	112	190	193	103	186	223	100	100
	1979	262	256	198	279	n.s.	194	160	219	160	154	262	282	250
	1980	174	182	153	130	n.s.	145	118	149	137	175	183	172	112
		Grain												
	1978	11	10	11	14	n.s.	14	11	12	18	12	12	23	21
	1979	19	16	16	17	n.s.	26	18	17	19	17	22	16	17
	1980	22	24	22	24	n.s.	23	25	26	29	17	23	29	19

(continued)

TABLE 3. (continued)

Param-eter	Year	Blount silt loam Ck	1/4 Max	1/2 Max	Max	LSD	Elliott silt loam Ck	1/4 Max	1/2 Max	Max	Plainfield loamy sand Ck	1/4 Max	1/2 Max	Max
		--mg/kg--												
		Leaf												
Mn	1978	28	30	28	26	n.s.	29	26	15	40	24	29	19	56
	1979	41	31	36	28	9**	42	42	29	41	37	35	25	55
	1980	40	30	38	29	8*	38	38	29	27	32	31	22	29
		Stover												
	1978	41	34	39	45	n.s.	29	32	23	50	28	27	20	36
	1979	37	39	40	38	n.s.	36	27	40	26	24	32	26	23
	1980	29	28	29	26	n.s.	26	24	23	22	22	21	19	14
		Grain												
	1978	4.0	3.6	4.0	4.0	n.s.	4.8	3.3	3.2	3.5	3.8	3.2	3.9	4.0
	1979	6.8	5.3	4.7	4.6	1.4**	7.4	5.5	4.7	3.2	5.3	7.5	4.0	3.4
	1980	7.5	7.2	7.7	7.2	n.s.	7.7	8.0	7.6	5.9	6.1	7.4	6.1	3.9

(continued)

TABLE 3. (continued)

Param-eter	Year	Blount silt loam Ck	1/4 Max	1/2 Max	Max	LSD	Elliott silt loam Ck	1/4 Max	1/2 Max	Max	Plainfield loamy sand Ck	1/4 Max	1/2 Max	Max
		mg/kg												
		Leaf												
Zn	1978	20	26	25	34	8**	19	30	27	279	20	45	51	246
	1979	32	46	50	62	16**	28	72	67	212	31	73	100	382
	1980	25	34	43	43	12**	26	42	56	148	28	42	52	124
		Stover												
	1978	51	35	34	32	n.s.	28	45	53	253	70	112	98	326
	1979	22	30	33	50	9**	17	40	46	210	12	53	88	244
	1980	23	32	41	49	18**	14	40	62	187	36	39	69	178
		Grain												
	1978	28	26	26	28	n.s.	26	28	31	53	34	37	38	45
	1979	19	19	18	20	n.s.	19	20	21	27	15	24	22	29
	1980	21	23	25	28	5**	21	26	33	36	21	25	28	34

(continued)

TABLE 3. (continued)

Parameter	Year	Blount silt loam Ck	Blount 1/4 Max	Blount 1/2 Max	Blount Max	Blount LSD	Elliott silt loam Ck	Elliott 1/4 Max	Elliott 1/2 Max	Elliott Max	Plainfield loamy sand Ck	Plainfield 1/4 Max	Plainfield 1/2 Max	Plainfield Max
		mg/kg												
		Leaf												
Cd	1978	0.4	1.1	1.9	3.1	0.4**	0.4	1.5	2.1	21.8	0.3	1.1	1.2	11.4
	1979	0.3	0.8	1.3	2.1	0.3**	0.4	1.1	2.0	19.3	0.4	1.6	2.2	17.3
	1980	0.2	0.4	1.0	1.0	0.6**	0.2	0.6	1.2	9.7	0.3	0.8	1.2	3.8
		Stover												
	1978	0.6	0.7	1.5	1.8	0.7**	0.4	0.7	1.5	25.0	0.7	1.3	1.3	13.3
	1979	0.4	1.1	1.9	2.8	0.6**	0.4	1.3	2.3	23.2	0.4	2.1	3.6	15.9
	1980	0.4	1.0	1.5	2.0	0.4**	0.4	0.8	2.4	16.3	0.8	1.3	1.7	8.2
		Grain												
	1978	<0.06	<0.06	<0.06	<0.06	n.s.	<0.06	<0.06	<0.06	0.66	<0.06	0.09	<0.06	0.28
	1979	<0.06	<0.06	<0.06	<0.06	n.s.	0.09	<0.06	<0.06	0.34	<0.06	<0.06	<0.06	0.18
	1980	<0.06	0.08	0.09	<0.06	n.s.	<0.06	<0.06	<0.06	0.40	<0.06	0.08	<0.06	0.28

(continued)

TABLE 3. (continued)

Parameter	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	Blount silt loam LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
		mg/kg												
		Leaf												
Cu	1978	3.4	3.8	3.9	4.5	0.5**	3.7	4.0	4.4	9.4	2.7	3.1	3.2	5.9
	1979	8.3	8.8	8.6	8.8	n.s.	8.6	9.1	8.4	10.3	5.8	7.5	8.4	9.9
	1980	8.5	8.6	8.9	8.7	n.s.	7.8	7.7	8.7	11.2	5.6	6.0	5.9	7.1
		Stover												
	1978	1.6	1.5	1.8	2.3	n.s.	1.8	1.7	2.0	3.5	1.8	2.6	2.0	4.1
	1979	6.3	6.3	6.2	7.3	n.s.	5.9	6.1	11.7	6.9	4.9	6.0	7.2	7.7
	1980	5.9	6.3	6.5	6.0	n.s.	4.7	5.8	6.6	6.3	3.8	5.2	5.7	6.2
		Grain												
	1978	1.4	1.3	1.5	1.6	n.s.	1.4	2.5	1.5	2.1	1.5	1.6	1.8	1.9
	1979	2.5	2.4	2.2	2.2	n.s.	2.6	2.0	2.7	1.8	1.8	3.0	2.3	1.9
	1980	2.0	2.1	2.1	2.1	n.s.	1.9	1.9	2.1	1.7	1.6	1.9	1.8	1.8

(Continued)

TABLE 3. (continued)

Parameter	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	Blount silt loam LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
		mg/kg												
		Leaf												
Ni	1978	<0.6	<0.6	<0.6	<0.6	n.s.	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	1.7
	1979	<0.6	<0.6	<0.6	<0.6	n.s.	<0.6	<0.6	<0.6	0.6	<0.6	1.6	<0.6	1.4
	1980	<0.6	<0.6	<0.6	<0.6	n.s.	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
		Stover												
	1978	0.7	<0.6	<0.6	<0.6	n.s.	<0.6	<0.6	0.7	1.0	0.8	0.9	<0.6	1.8
	1979	<0.6	<0.6	0.9	<0.6	n.s.	<0.6	<0.6	<0.6	0.7	0.6	<0.6	1.2	1.4
	1980	<0.6	<0.6	<0.6	<0.6	n.s.	0.7	<0.6	0.7	<0.6	<0.6	<0.6	<0.6	1.0
		Grain												
	1978	0.6	<0.6	<0.6	<0.6	n.s.	<0.6	0.9	0.7	1.1	<0.6	<0.6	0.6	2.2
	1979	<0.6	<0.6	<0.6	<0.6	n.s.	<0.6	<0.6	<0.6	0.9	<0.6	<0.6	<0.6	1.4
	1980	<0.6	0.6	<0.6	<0.6	n.s.	<0.6	0.8	<0.6	1.5	<0.6	<0.6	1.3	1.4

(continued)

TABLE 3. (continued)

Parameter	Year	Blount silt loam Ck	Blount 1/4 Max	Blount 1/2 Max	Blount Max	LSD	Elliott silt loam Ck	Elliott 1/4 Max	Elliott 1/2 Max	Elliott Max	Plainfield loamy sand Ck	Plainfield 1/4 Max	Plainfield 1/2 Max	Plainfield Max
		mg/kg												
		Leaf												
Cr	1978	<0.6	<0.6	<0.6	<0.6	n.s.	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
	1979	<0.6	<0.6	<0.6	<0.6	n.s.	<0.6	0.7	<0.6	0.6	0.7	0.6	0.8	<0.6
	1980	<0.1	0.2	<0.1	0.2	n.s.	<0.1	<0.1	<0.1	0.2	0.2	0.6	<0.1	0.3
		Stover												
	1978	0.9	0.9	1.0	<0.6	n.s.	<0.6	1.3	<0.6	<0.6	<0.6	2.3	<0.6	<0.6
	1979	1.3	1.0	1.8	2.1	n.s.	0.7	0.7	1.2	1.1	1.1	1.9	3.0	1.2
	1980	0.7	0.8	0.9	<0.6	n.s.	0.8	<0.6	0.8	1.2	0.9	<0.6	0.9	0.9
		Grain												
	1978	0.2	0.1	0.2	0.3	n.s.	0.7	<0.1	0.2	0.2	0.2	0.2	0.2	0.2
	1979	0.2	0.2	0.2	0.2	n.s.	0.1	<0.1	0.2	<0.1	0.1	0.2	0.2	0.3
	1980	<0.1	<0.1	<0.1	<0.1	n.s.	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1

(continued)

TABLE 3. (continued)

Parameter	Year	Blount silt loam					Elliott silt loam				Plainfield loamy sand			
		Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
		mg/kg												
		Leaf												
Pb	1978	1.3	1.3	1.4	1.5	n.s.	1.5	1.7	1.4	1.3	1.3	1.6	1.7	1.7
	1979	1.0	1.0	1.2	0.9	n.s.	1.1	0.9	0.9	1.2	1.8	1.0	1.2	1.6
	1980	<0.6	<0.6	<0.6	<0.6	n.s.	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
		Stover												
	1978	1.3	1.4	1.5	1.5	n.s.	1.3	1.9	2.0	1.2	3.2	3.4	2.1	3.0
	1979	2.9	3.3	3.4	3.8	n.s.	3.3	2.5	2.7	2.5	3.3	4.3	4.3	3.0
	1980	2.2	2.7	3.0	3.3	n.s.	3.6	3.3	1.6	2.3	4.5	4.6	3.5	3.2
		Grain												
	1978	0.8	<0.6	<0.6	1.4	n.s.	<0.6	<0.6	0.7	<0.6	<0.6	<0.6	0.7	2.4
	1979	1.3	<0.6	1.7	<0.6	1.0*	1.0	0.8	<0.6	<0.6	1.0	<0.6	0.8	2.1
	1980	<0.6	<0.6	<0.6	<0.6	n.s.	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6

a/ Concentrations were calculated on a dry weight basis.
b/ All three soil types were represented in a north series.
*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

of time is longer for higher concentrations accumulated in soils by additional years of similar incremental annual applications. The availability of Cd and Zn for uptake by corn decreased by about 50% during the first year after sludge applications were suspended, then more slowly thereafter. Concentrations of trace elements in corn plant tissues were not significantly affected by fertilizing sludge-amended soil with inorganic sources of N nor was the trend toward lower uptakes of Cd and Zn with time affected.

There was no indication that soil types influenced uptake of sludge-borne Cd and Zn by corn nor their decreased availability with time after sludge applications were terminated.

Since soil pH was significantly lower in plots amended with higher amounts of sludge, further work is needed to see how pH adjustment would affect the uptake of Cd and Zn and the rate at which these metals are converted to unavailable forms.

Further work is needed to see if renewed annual applications of sludge would convert unavailable sources of Cd and Zn in soils to forms more available for uptake by plants.

RESPONSE OF CONTINUOUS CORN ON BLOUNT SILT LOAM TO REPEATED ANNUAL APPLICATIONS OF SEWAGE SLUDGE

Introduction

This report contains the results for the last three years of a 13-year study involving the annual irrigation of corn with digested sewage sludge, which was initiated in 1968. Results obtained during the first ten years were reported previously (Hinesly et al., 1981).

Materials and Methods

Anaerobically digested sewage sludge from Chicago, Illinois was annually applied by furrow irrigation of corn, growing on ridges, in replicated (four) plots (6.1 x 12 m) of Blount silt loam soil located on the northeast Agronomy Research Center near Elwood, Illinois. Sludge applications of 0, 6.4, 12.7, and 25.4 mm, randomized within blocks, were made as soon and as often as weather conditions permitted after plants reached a height of about 15 cm. Prior to spring tillage operations, all plots received broadcast applications of KCl to supply 134 kg K/ha. Control plots were also fertilized with 268 kg N/ha and 134 kg P/ha.

At the beginning and end of each irrigation event samples of digested sludge were collected, dried at 110°C for 24 hours, and ground to pass an 80-mesh screen. Soil samples were collected each spring after the first tillage to a depth of 76 cm using stainless steel tubes. Soil cores were segmented into 15.2 cm lengths, composited for a particular depth, dried (60°C), crushed, split, and pulverized to pass a 60-mesh screen. Sludge and soil samples (0.1 and 0.5 g, respectively) were heated to 500°C for 24 hours, digested in concentrated HCl-HF, and dissolved in 0.1 N HCl for analysis by atomic absorption spectrophotometry to determine metal concentrations.

When about 10% of the plants had tasseled, leaves opposite and below the primary ear shoots were collected from the two center rows of each plot, washed in distilled water, dried at 60°C and ground in a Wiley mill to pass a 20-mesh screen. Subsamples of grain, hand-harvested from the two center rows to determine yields, were dried and ground in the same manner as leaf samples. Leaf and grain samples (2 g) were digested in concentrated HNO_3 at 90°C, followed by $HClO_4$ at 200°C, taken to dryness, dissolved in 0.1 N HNO_3, and analyzed for metal concentrations by atomic absorption spectrophotometry.

Phosphorus concentrations in solutions of digested materials were determined colorimetrically using a vanadomolybdate finish. Total organic-C concentrations in soil were determined by the Walkley-Black procedure (Allison, 1965). Soil cation exchange capacities (CEC) were determined by the ammonium saturation method (Chapman, 1965). Total nitrogen concentrations were determined by a semimicro-Kjeldahl method (Bremner, 1965).

The study protocol, as described in the previous report, remained unchanged during the last three years, with one exception. Because corn hybrids have different inherited capacities to take up trace elements, seed of one hybrid (Pioneer 3517) had been used each year since the study was initiated. But in 1980, it was learned that this hybrid would no longer be marketed and was being replaced by the new hybrid 3541. Toward maintaining continuity of results, enough seed of hybrid 3517 was purchased to plant split-plots (4 rows) for three years so that comparison of results with those from hybrid 3541 could be made. Hybrid 3541, planted for the first time in 1980, will be planted on the other half of split-plots during each of two additional years. Knowing the relationship between the responses of the two hybrids to sludge irrigation will permit the evaluation of long-term effects without the confounding effects that generally occur in such studies when different hybrids, cultivars, or varieties are substituted.

Results and Discussion

Amounts of liquid digested sludge, applied by furrow irrigation, on maximum-treated plots, during the last three years, ranged from 12.7 to 17.8 cm and supplied equivalent dry weight solids loading rates that ranged from 45.8 to 68.4 mt/ha (Table 4). Appropriately lesser amounts were applied on the same days on 1/4- and 1/2-maximum-treated plots. Concentrations of various chemical constituents of digested sludge are presented in Table 5, along with total equivalent dry weights of these constituents applied during a particular year. On maximum-treated plots N and P were applied at rates that were about ten fold amounts needed to satisfy nutrient requirements of corn. Slightly less than half of the total N was in the readily available NH_4-N form (Table 6). At the end of the 1980 growing season 185, 1,018, 2,186, 264, 768, and 3,652 kg/ha of sludge-borne Cd, Cu, Cr, Ni, Pb, and Zn, respectively, had been applied on maximum-sludge-treated plots during the total 13 year study. The chemical composition of Blount silt loam was markedly changed by long-term applications of sewage sludge.

TABLE 4. ANNUAL DIGESTED SLUDGE LOADING RATES AND TOTAL ACCUMULATIONS ON MAXIMUM-SLUDGE-TREATED BLOUNT SILT LOAM PLOTS PLANTED TO CORN.

	Liquid Sludge Applied (cm)		Dry Solids Applied (mt/ha)	
Year	Annual	Accumulations	Annual	Accumulations
1978	17.8	225.4	68.4	625.0
1979	15.2	240.6	62.5	687.5
1980	12.7	253.3	45.8	733.3

Concentrations of selected chemical elements at various depths of Blount with and without sludge are presented in Table 7. Organic-C and total N contents were markedly increased in the 0 to 30 cm depth of soil by sludge applications. However, there is no evidence that either organic-C or N continued to accumulate to higher levels in Blount with successive years of sludge applications. Apparently, for any sludge loading rate, an equilibrium between additions and decompositional losses of organic matter was maintained throughout the additional three years of study. Some variation in organic-C and N contents existed between years because sludge composition and loading rates were not always the same, climatic factors affecting decompositional processes varied from year to year, and soil samples were not collected each year at precisely the same time. Nevertheless, these data leave little doubt that organic matter contents of Blount will not be increased further without drastically increasing sludge loading rates.

Concentrations of P were markedly increased in the 0 to 30 cm depth of soil by sludge applications, but those for K, Na, Ca, Mg, Fe, and Mn were not affected (Table 7). Concentrations of all the transition and heavy metals such as Cd, Cu, Cr, Ni, Pb, and Zn were significantly increased in the 0 to 30 cm soil depth. There was some indication that Cd and Zn concentrations may have been increased at soil depths below 30 cm.

Limestone applications were not made during the last 3 years of the study. As expected, maximum sludge applications caused a significant reduction in soil pH, when compared to values from control and 1/4-maximum-sludge-treated plots. Maximum sludge applications tended to lower pH throughout the soil profile (Table 7).

The intent was to obtain plant populations of about 60,000 plants per hectare, and, as can be seen in Table 8, the number of plants did not vary significantly from this value for any of the plots. Grain yields were increased by sludge applications during the first two years of the continuation study, but during the last year treatments had no effect on yields for either of the two hybrids. Due to hot, dry weather, grain yields were significantly less in the last year of the study (Tables 8 and 9). However, stover yields were somewhat higher during the year of lowest grain yields and were increased by higher sludge applications, regardless of hybrid. Lower grain yields were perhaps due to weather conditions that adversely affected pollination.

TABLE 5. AVERAGE CONTENTS AND TOTAL ANNUAL AMOUNTS OF SEVERAL CONSTITUENTS OF SLUDGE APPLIED ON THE MAXIMUM-TREATED BLOUNT SILT LOAM PLOTS PLANTED TO CORN. APPROPRIATELY LESSER AMOUNTS OF SLUDGE FROM THE SAME BATCH WERE APPLIED ON OTHER SLUDGE-TREATED PLOTS ON THE SAME DAY.

Year	Solids	Total N	P	K	Na	Ca	Mg	Fe	Mn	Cd	Cu	Cr	Ni	Pb	Zn
	-- % --														
		Annual Means of Analytes in Sludge (mg/kg wet weight)													
1978	3.86	2097	1010	180	87	1240	505	1530	25	10.5	62	108	17.8	34	149
1979	4.06	2227	1070	225	101	1160	495	1780	22	10.0	67	106	17.0	31	146
1980	3.61	2290	1022	234	132	1360	572	1470	21	7.6	56	96	15.9	27	125
		Amounts of Analytes Applied as Constituents of Sludge (kg/ha dry weight)													
1978		3725	1790	320	154	2200	897	2720	44	19	110	192	32	60	265
1979		3956	1900	400	179	2060	879	3160	38	18	119	188	30	55	259
1980		2906	1296	297	168	1726	725	1868	26	10	70	122	20	34	159

TABLE 6. AVERAGE CONTENTS AND TOTAL AMOUNTS OF VARIOUS FORMS OF N AND ASH CONTENTS OF SOLIDS ANNUALLY APPLIED AS CONSTITUENTS OF SLUDGE ON BLOUNT SILT LOAM.

Year	% Ash	Total N	NH_4-N	NO_3-N
		Annual Means of Analytes in Sludge (mg/kg wet weight)		
1978	51.9	2097	1020	7.8
1979	48.6	2227	1055	14.4
1980	51.1	2290	1071	4.4
		Amounts of Analytes Applied as Constituents of Sludge (kg/ha dry weight)		
1978	-	3725	1812	14
1979	-	3956	1874	25
1980	-	2906	1359	6

Except for Cd, Cu, Ni, and Zn, concentrations of most of the selected elements in leaves, grain, and stover, were not consistently affected by sludge applications (Table 10). In view of the exceedingly high rates of sludge-borne N, it is remarkable that N contents in plant tissues were never markedly increased, although small, significant increases were observed in some years. This was also the situation for P contents of plant tissues. Except for Cd, there was no evidence that concentrations of trace elements in corn plant tissues differed between the two hybrids used during the last year of the study. Neither was there any indication that trace element concentrations in plant tissues increased as a result of long-term accumulations of sludge-borne metals in Blount.

Summary and Conclusions

During the last three years of the 13 year study, there was no indication that a phytotoxic condition was imminent. Except for the continual build up of transition and heavy metal concentrations in sewage sludge-treated soil, there were few changes in the chemical properties of Blount.

As was previously reported, uptake of Cd, Cu, Ni, and Zn were correlated with annual sludge-borne applications of these metals on Blount.

The new corn hybrid, planted in the last year, took up only about 1/2 as much Cd as the hybrid that had been used throughout the study. Both of these hybrids were selected on the basis of their potential to produce high yields when grown in the region within which the Northeast Agronomy Research Center is located. Since the parents of these hybrids were unknown outside the seed company, their capacities to take up metals were not known a priori. However, it was obvious from results obtained during the one-year of compari-

TABLE 7. CONCENTRATIONS OF TOTAL MACRO- AND TRACE- ELEMENTS, ORGANIC-C, AND pH DETERMINED FROM SOIL SAMPLES COLLECTED AT DEPTHS OF 0 TO 15, 15 TO 30, 30 TO 46, AND 61 TO 76 cm IN BLOUNT SILT LOAM PLOTS.[a/][b/][c/]

Parameter	Depth cm	Year	Sludge Application Rates 0	1/4 Max	1/2 Max	Max	LSD
			%				
Organic C	0-15	1978	1.37	1.68	2.29	2.90	0.65**
		1979	1.38	1.87	2.60	3.36	0.27**
		1980	1.37	1.66	2.44	3.21	0.44**
	15-30	1978	0.99	1.31	1.55	2.05	0.31**
		1979	0.89	1.18	1.41	1.80	0.40**
		1980	0.84	1.07	1.32	1.85	0.36**
	30-46	1978	0.35	0.44	0.47	0.40	n.s.
		1979	0.42	0.47	0.44	0.44	n.s.
	61-76	1978	0.47	0.44	0.49	0.38	n.s.
		1979	0.45	0.41	0.48	0.45	n.s.
N	0-15	1978	0.133	0.151	0.200	0.279	0.040**
		1979	0.135	0.168	0.193	0.290	0.057**
		1980	0.134	0.141	0.205	0.257	0.085**
	15-30	1978	0.105	0.131	0.125	0.204	0.054**
		1979	0.090	0.113	0.130	0.173	0.027**
		1980	0.085	0.104	0.121	0.168	0.031**
	30-46	1978	0.058	0.063	0.064	0.061	n.s.
		1979	0.048	0.065	0.060	0.055	n.s.
	61-76	1978	0.060	0.060	0.066	0.054	n.s.
		1979	0.055	0.055	0.060	0.058	n.s.
P	0-15	1978	.081	.116	.198	.333	.061**
		1979	.094	.144	.250	.391	.046**
		1980	.080	.140	.223	.356	.048**
	15-30	1978	.045	.074	.111	.182	.023**
		1979	.045	.086	.109	.194	.033**
		1980	.047	.078	.113	.186	.047**
	30-46	1978	.026	.031	.033	.028	n.s.
		1979	.032	.034	.033	.033	n.s.
	61-76	1978	.032	.033	.034	.028	n.s.
		1979	.035	.036	.037	.034	n.s.

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Sludge Application Rates 0	1/4 Max	1/2 Max	Max	LSD
			%				
K	0-15	1978	1.87	1.88	1.88	1.82	n.s.
		1979	1.96	1.99	1.93	1.89	n.s.
		1980	2.02	1.92	1.90	1.86	n.s.
	15-30	1978	1.95	1.92	1.93	1.87	n.s.
		1979	1.97	1.95	1.80	1.93	n.s.
		1980	1.92	1.90	1.91	1.88	n.s.
	30-46	1978	2.08	1.95	2.02	1.96	n.s.
		1979	2.08	1.96	1.97	1.94	n.s.
	61-76	1978	2.64	2.51	2.56	2.43	n.s.
		1979	2.51	2.61	2.77	2.69	0.140*
Na	0-15	1978	0.814	0.798	0.790	0.778	0.024*
		1979	0.807	0.758	0.734	0.736	n.s.
		1980	0.854	0.819	0.812	0.838	n.s.
	15-30	1978	0.767	0.761	0.736	0.748	n.s.
		1979	0.669	0.703	0.653	0.706	n.s.
		1980	0.726	0.734	0.741	0.736	n.s.
	30-46	1978	0.609	0.634	0.634	0.684	n.s.
		1979	0.513	0.529	0.552	0.515	n.s.
	61-76	1978	0.469	0.472	0.461	0.519	n.s.
		1979	0.432	0.516	0.493	0.503	n.s.
Ca	0-15	1978	0.502	0.630	0.560	0.640	n.s.
		1979	0.493	0.542	0.509	0.552	n.s.
		1980	0.509	0.613	0.568	0.618	n.s.
	15-30	1978	0.476	0.514	0.518	0.517	n.s.
		1979	0.401	0.499	0.475	0.500	n.s.
		1980	0.377	0.428	0.413	0.425	n.s.
	30-46	1978	0.341	0.388	0.332	0.343	n.s.
		1979	0.236	0.270	0.290	0.263	n.s.
	61-76	1978	0.783	0.418	0.620	0.598	n.s.
		1979	1.44	0.819	0.620	0.556	0.599*

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Sludge Application Rates 0	1/4 Max	1/2 Max	Max	LSD
			--------	--------	%	--------	--------
Mg	0-15	1978	0.368	0.459	0.395	0.396	n.s.
		1979	0.347	0.381	0.363	0.349	n.s.
		1980	0.384	0.458	0.412	0.409	n.s.
	15-30	1978	0.427	0.414	0.431	0.365	n.s.
		1979	0.411	0.393	0.346	0.382	n.s.
		1980	0.512	0.494	0.463	0.474	n.s.
	30-46	1978	0.691	0.620	0.587	0.538	n.s.
		1979	0.635	0.577	0.591	0.555	n.s.
	61-76	1978	0.993	0.698	0.950	0.834	n.s.
		1979	1.25	1.02	0.992	0.955	n.s.
Fe	0-15	1978	1.82	2.00	2.03	2.06	n.s.
		1979	1.87	2.08	2.10	2.11	n.s.
		1980	1.86	1.86	1.98	1.82	n.s.
	15-30	1978	2.11	2.03	2.04	2.05	n.s.
		1979	2.31	2.02	2.15	2.08	n.s.
		1980	2.64	2.36	2.28	2.44	n.s.
	30-46	1978	3.92	3.19	3.32	3.03	n.s.
		1979	4.06	3.72	3.70	3.65	n.s.
	61-76	1978	4.40	4.40	4.62	4.20	n.s.
		1979	4.12	4.37	4.31	4.36	n.s.
			--------	--------	mg/kg	--------	--------
Mn	0-15	1978	863	1065	953	961	n.s.
		1979	1210	1350	1280	1050	n.s.
		1980	947	930	906	886	n.s.
	15-30	1978	805	864	786	948	n.s.
		1979	748	753	789	942	n.s.
		1980	625	702	747	664	n.s.
	30-46	1978	418	400	389	400	n.s.
		1979	442	398	412	414	n.s.
	61-76	1978	628	670	603	474	n.s.
		1979	667	672	751	667	n.s.

TABLE 7. (continued)

Parameter	Depth cm	Year	Sludge Application Rates 0	1/4 Max	1/2 Max	Max	LSD
			mg/kg				
Zn	0-15	1978	79	179	305	521	98**
		1979	82	225	379	578	67**
		1980	76	220	352	536	63**
	15-30	1978	74	146	219	362	48**
		1979	78	141	183	315	62**
		1980	72	129	194	317	54**
	30-46	1978	80	82	91	98	4*
		1979	86	87	91	104	n.s.
	61-76	1978	103	107	111	109	n.s.
		1979	102	108	110	120	11**
Cd	0-15	1978	0.6	5.6	13.0	24.6	5.6**
		1979	0.5	8.0	16.3	28.4	3.1**
		1980	0.6	8.4	15.4	25.8	3.1**
	15-30	1978	0.4	4.1	7.6	15.6	2.6**
		1979	<0.25	3.7	6.0	13.1	3.1**
		1980	<0.25	3.2	6.2	13.5	3.2**
	30-46	1978	<0.25	0.45	0.46	0.52	n.s.
		1979	<0.25	<0.25	<0.25	<0.25	n.s.
	61-76	1978	<0.25	<0.25	0.30	<0.25	0.18*
		1979	<0.25	<0.25	<0.25	<0.25	n.s.
Cu	0-15	1978	15	48	86	151	27**
		1979	18	50	92	162	33**
		1980	20	68	113	168	19**
	15-30	1978	19	34	58	102	25**
		1979	20	40	64	112	16**
		1980	21	38	55	101	21**
	30-46	1978	27	26	30	25	n.s.
		1979	36	33	34	32	n.s.
	61-76	1978	31	33	41	36	n.s.
		1979	41	43	41	44	n.s.

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Sludge Application Rates 0	1/4 Max	1/2 Max	Max	LSD
			mg/kg				
Ni	0-15	1978	14	19	28	36	14**
		1979	14	23	34	47	7**
		1980	15	24	37	53	7**
	15-30	1978	16	20	25	32	5**
		1979	13	14	16	24	8**
		1980	19	24	26	38	6**
	30-46	1978	28	23	27	22	n.s.
		1979	27	23	23	22	n.s.
	61-76	1978	49	43	47	45	n.s.
		1979	43	44	50	45	n.s.
Cr	0-15	1978	40	120	205	341	51*
		1979	36	101	171	270	42**
		1980	31	78	143	254	58**
	15-30	1978	43	94	135	222	42**
		1979	39	68	90	157	31**
		1980	30	60	74	114	33**
	30-46	1978	46	47	58	61	10**
		1979	48	46	45	45	n.s.
	61-76	1978	71	74	76	69	n.s.
		1979	63	59	64	62	n.s.
Pb	0-15	1978	21	43	74	121	23**
		1979	28	60	99	144	16**
		1980	20	52	83	127	16**
	15-30	1978	22	37	53	83	12**
		1979	22	35	44	73	15**
		1980	22	36	48	80	11**
	30-46	1978	23	27	25	26	n.s.
		1979	19	18	18	19	n.s.
	61-76	1978	28	26	31	25	n.s.
		1979	23	22	21	21	n.s.

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Sludge Application Rates 0	1/4 Max	1/2 Max	Max	LSD
			--Units--				
pH	0-15	1978	5.9	6.6	6.1	5.7	0.6**
		1979	6.3	6.8	6.3	6.1	0.5*
		1980	6.2	6.7	6.0	5.9	0.5*
	15-30	1978	5.9	6.4	5.9	5.8	n.s.
		1979	5.8	6.2	5.8	5.6	0.4*
		1980	5.2	5.7	5.5	5.4	n.s.
	30-46	1978	4.5	4.6	4.4	4.3	0.2**
		1979	4.6	4.5	4.4	4.2	0.2*
	61-76	1978	6.2	5.2	5.6	5.0	n.s.
		1979	7.4	6.4	6.5	5.6	0.9*

a/ Concentrations are on a dry weight basis

b/ Digested sludge was applied annually on replicated plots at various rates and control or check plots were annually treated with a relatively high rate of inorganic fertilizer.

c/ Samples were collected from plots identified as the NW 800 series.

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

n.s. = non-significant F-test.

TABLE 8. PLANT POPULATIONS AND CORN GRAIN AND STOVER YIELDS FROM PLOTS DESIGNATED NW 800.

Year	Sludge Application Rates				
	0	1/4 Max	1/2 Max	Max	LSD
	Population				
	1,000 plants/ha — Pioneer 3517				
1978	56.2	54.9	57.8	59.3	
1979	61.9	63.6	59.3	63.0	
1980	59.5	61.5	62.1	59.2	
	Pioneer 3541				
1980	61.5	59.5	61.5	59.2	
	Grain Yields				
	mt/ha (15.5% moisture) — Pioneer 3517				
1978	5.73	6.24	6.54	7.32	0.807**
1979	8.51	8.93	9.76	9.22	0.820*
1980	3.50	3.17	2.33	2.63	n.s.
	Pioneer 3541				
1980	2.53	2.69	2.76	3.54	n.s.
	Stover Yields				
	mt/ha (dry weight) — Pioneer 3517				
1978	8.02	9.84	8.35	9.50	n.s.
1979	9.41	11.1	10.6	9.80	n.s.
1980	9.86	11.5	12.5	13.2	2.42**
	Pioneer 3541				
1980	8.84	9.36	10.4	11.4	1.60*

n.s. = no significant differences.
*, ** = significant different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 9. AVERAGE RAINFALL AT THE NORTHEAST AGRONOMY RESEARCH CENTER DURING THE 3 GROWING SEASONS. THE 1941 TO 1970 AVERAGE RAINFALL FOR THE AREA IS PRESENTED FOR COMPARISON.

	Month						
Year	April	May	June	July	August	September	Totals
	Rainfall in cm						
1978	9.0	9.0	20.8	5.7	2.8	3.2	50.5
1979	11.5	5.0	10.8	13.2	15.5	0.1	56.1
1980	5.8	10.4	8.8	9.2	19.6	20.8	74.5
1941-1970 Average	9.4	9.1	10.4	9.8	7.7	8.4	54.8

son that if the new hybrid (Pioneer 3541) was grown on soils amended with sludge at agronomic N rates, concentrations of Cd in plant tissues would present little, if any, impact on human food chains. Results from this accidental choice of a hybrid with a low capacity to take up or translocate Cd to above ground parts reinforces previous conclusions that plant hybrids and cultivars can be selected and/or developed that would eliminate the potential health hazard associated with the uptake of Cd from sewage sludge-amended soils (Hinesly et al., 1981).

Total amounts of transition and heavy metals applied on the surface of Blount as constituents of sewage sludge could not be accounted for within soil depths of 76 cm. Further work is needed to determine how about 40% of the sludge-borne metals were lost.

RESPONSES OF WINTER WHEAT AND SOYBEANS ON BLOUNT PREVIOUSLY AMENDED WITH ANNUAL APPLICATIONS OF SEWAGE SLUDGE

Introduction

Other researchers have speculated that the uptake of transition and heavy metals by crop plants may increase with time, after sewage sludges are admixed with soils, as a result of their release when organic matter decomposes (Chaney, 1973; Sims and Boswell, 1978). It was assumed that with time the release of sludge-borne metals would create phytotoxic conditions and/or increase levels of metals in plant produce that would adversely affect animal and human health.

The purpose of this study was to measure the effects of sludge-borne metals on the growth and quality of wheat (*Triticum aestivium* L.) and soybeans (*Glycine max* L.) where sludge applications had been terminated.

TABLE 10. AVERAGE CONTENTS OF MACROELEMENTS AND MINOR ELEMENTS IN CORN LEAF, STOVER, AND GRAIN TISSUE SAMPLES FROM BLOUNT SILT LOAM PLOTS.

Constituent	Year	Sludge Treatment: 0	1/4 Max	1/2 Max	Max	LSD
		%				
		Pioneer 3517 Leaf				
N	1978	3.42	3.12	3.21	3.42	0.22*
	1979	3.04	3.04	3.34	3.07	n.s.
	1980	2.74	2.79	2.89	2.94	0.16**
		Pioneer 3541 Leaf				
	1980	2.87	2.89	2.83	3.08	0.19**
		Pioneer 3517 Stover				
	1978	0.60	0.68	0.85	0.92	n.s.
	1979	1.03	1.08	1.10	1.18	n.s.
	1980	1.56	1.56	1.58	1.83	n.s.
		Pioneer 3541 Stover				
	1980	1.76	1.73	1.92	1.78	n.s.
		Pioneer 3517 Grain				
	1978	1.77	1.76	1.80	1.77	n.s.
	1979	1.64	1.61	1.48	1.78	n.s.
	1980	1.46	2.01	1.94	1.84	0.37*
		Pioneer 3541 Grain				
	1980	1.81	1.34	1.88	1.84	n.s.

(continued)

TABLE 10. (continued)

Constituent	Year	Sludge Treatment: 0	1/4 Max	1/2 Max	Max	LSD
		--------	--------	%	--------	--------
		Pioneer 3517 Leaf				
P	1978	0.355	0.326	0.352	0.378	n.s.
	1979	0.386	0.362	0.404	0.390	n.s.
	1980	0.321	0.304	0.311	0.363	0.017**
		Pioneer 3541 Leaf				
	1980	0.280	0.257	0.276	0.319	0.014**
		Pioneer 3517 Stover				
	1978	0.083	0.084	0.124	0.174	0.052**
	1979	0.156	0.157	0.166	0.231	n.s.
	1980	0.102	0.102	0.096	0.107	n.s.
		Pioneer 3541 Stover				
	1980	0.274	0.280	0.297	0.324	n.s.
		Pioneer 3517 Grain				
	1978	0.317	0.289	0.309	0.334	n.s.
	1979	0.356	0.350	0.370	0.347	n.s.
	1980	0.376	0.380	0.370	0.374	n.s.
		Pioneer 3541 Grain				
	1980	0.362	0.328	0.332	0.323	0.025*

(continued)

TABLE 10. (continued)

Constituent	Year	Sludge Treatment: 0	1/4 Max	1/2 Max	Max	LSD
		%				
		Pioneer 3517 Leaf				
Ca	1978	0.884	0.756	0.657	0.721	0.119*
	1979	0.734	0.696	0.746	0.729	n.s.
	1980	0.526	0.563	0.581	0.562	n.s.
		Pioneer 3541 Leaf				
	1980	0.542	0.547	0.560	0.581	n.s.
		Pioneer 3517 Stover				
	1978	0.347	0.353	0.301	0.358	0.048*
	1979	0.443	0.390	0.456	0.549	0.115**
	1980	0.403	0.420	0.344	0.426	n.s.
		Pioneer 3541 Stover				
	1980	0.295	0.273	0.321	0.375	n.s.
		mg/kg				
		Pioneer 3517 Grain				
	1978	28	30	30	31	n.s.
	1979	21	31	21	25	n.s.
	1980	41	41	32	44	n.s.
		mg/kg				
		Pioneer 3541 Grain				
	1980	41	33	33	33	n.s.

(continued)

TABLE 10. (continued)

Constituent	Year	Sludge Treatment: 0	1/4 Max	1/2 Max	Max	LSD
		%				
		Pioneer 3517 Leaf				
Mg	1978	0.241	0.242	0.219	0.209	n.s.
	1979	0.223	0.214	0.210	0.210	n.s.
	1980	0.265	0.288	0.263	0.263	n.s.
		Pioneer 3541 Leaf				
	1980	0.308	0.320	0.299	0.278	0.027*
		Pioneer 3517 Stover				
	1978	0.171	0.206	0.179	0.187	n.s.
	1979	0.205	0.221	0.203	0.216	n.s.
	1980	0.231	0.254	0.202	0.220	n.s.
		Pioneer 3541 Stover				
	1980	0.157	0.170	0.187	0.178	n.s.
		Pioneer 3517 Grain				
	1978	0.127	0.119	0.121	0.127	n.s.
	1979	0.145	0.133	0.138	0.126	n.s.
	1980	0.155	0.158	0.148	0.149	n.s.
		Pioneer 3541 Grain				
	1980	0.141	0.131	0.128	0.124	0.011*

(continued)

TABLE 10. (continued)

Constituent.	Year	0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
		Pioneer 3517 Leaf				
Fe	1978	120	103	126	106	n.s.
	1979	118	111	115	115	n.s.
	1980	124	119	118	117	n.s.
		Pioneer 3541 Leaf				
	1980	128	120	116	124	8*
		Pioneer 3517 Stover				
	1978	105	114	129	103	n.s.
	1979	128	121	130	135	n.s.
	1980	129	147	100	104	n.s.
		Pioneer 3541 Stover				
	1980	120	112	172	113	n.s.
		Pioneer 3517 Grain				
	1978	16	20	20	24	5**
	1979	22	25	32	25	n.s.
	1980	25	27	25	32	5*
		Pioneer 3541 Grain				
	1980	30	31	30	31	n.s.

(continued)

TABLE 10. (continued)

Constituent	Year	Sludge Treatment: 0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
		Pioneer 3517 Leaf				
Mn	1978	75	50	46	60	n.s.
	1979	69	35	38	44	19*
	1980	103	44	56	63	n.s.
		Pioneer 3541 Leaf				
	1980	100	52	56	65	32*
		Pioneer 3517 Stover				
	1978	59	48	42	56	n.s.
	1979	70	48	52	67	n.s.
	1980	55	32	44	48	12*
		Pioneer 3541 Stover				
	1980	58	32	37	46	16*
		Pioneer 3517 Grain				
	1978	5.4	4.4	4.0	4.0	1.0**
	1979	9.6	6.6	6.4	5.7	2.2**
	1980	9.0	6.8	5.9	7.4	2.0*
		Pioneer 3541 Grain				
	1980	7.8	6.1	5.6	5.9	0.8**

(continued)

TABLE 10. (continued)

Constituent	Year	Sludge Treatment: 0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
		Pioneer 3517 Leaf				
Zn	1978	73	139	216	308	63**
	1979	59	130	247	330	61**
	1980	57	125	209	289	50**
		Pioneer 3541 Leaf				
	1980	44	98	190	288	50**
		Pioneer 3517 Stover				
	1978	39	127	248	350	54**
	1979	26	146	234	348	93**
	1980	52	156	370	393	162**
		Pioneer 3541 Stover				
	1930	62	172	312	396	88**
		Pioneer 3517 Grain				
	1978	30	39	50	58	6**
	1979	26	42	49	49	9**
	1980	28	42	48	58	8**
		Pioneer 3541 Grain				
	1980	33	41	48	52	8**

(Continued)

TABLE 10. (continued)

Constituent	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
		Pioneer 3517 Leaf				
Cd	1978	0.8	9.0	17.3	20.0	6.8**
	1979	0.4	7.7	21.2	33.8	11.5**
	1980	0.4	5.6	14.7	22.7	3.8**
		Pioneer 3541 Leaf				
	1980	0.208	0.958	3.45	7.72	1.10**
		Pioneer 3517 Stover				
	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 Stover				
	1980	0.484	3.76	8.61	14.1	2.46**
		Pioneer 3517 Grain				
	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 Grain				
	1980	<0.062	<0.062	0.111	0.171	0.086**

(continued)

TABLE 10. (continued)

Constituent	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
		----------mg/kg----------				
		Pioneer 3517 Leaf				
Cu	1978	10.4	11.5	14.0	17.3	2.6**
	1979	9.4	11.0	11.6	12.5	1.6**
	1980	7.7	9.8	10.1	12.9	1.9**
		Pioneer 3541 Leaf				
	1980	8.37	10.5	11.2	13.2	0.91**
		Pioneer 3517 Stover				
	1978	2.9	3.8	5.0	5.1	1.2**
	1979	6.0	7.2	7.3	8.9	n.s.
	1980	4.5	6.4	6.6	6.8	1.6*
		Pioneer 3541 Stover				
	1980	5.40	7.26	6.95	7.19	0.94**
		Pioneer 3517 Grain				
	1978	2.0	2.2	2.1	1.7	0.3*
	1979	2.2	2.3	2.4	2.0	n.s.
	1980	1.8	1.8	1.5	1.5	n.s.
		Pioneer 3541 Grain				
	1980	1.58	1.69	1.56	1.52	n.s.

(continued)

TABLE 10. (continued)

Constituent	Year	Sludge Treatment 0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
		Pioneer 3517 Leaf				
Ni	1978	<0.6	<0.6	0.9	1.2	0.5**
	1979	<0.6	<0.6	<0.6	1.3	0.4**
	1980	<0.6	<0.6	<0.6	0.9	0.4*
		Pioneer 3541 Leaf				
	1980	<0.6	<0.6	<0.6	0.7	n.s.
		Pioneer 3517 Stover				
	1978	0.9	0.8	2.2	2.4	n.s.
	1979	<0.6	<0.6	<0.6	1.7	0.4**
	1980	<0.6	<0.6	1.0	2.4	0.8**
		Pioneer 3541 Stover				
	1980	<0.6	<0.6	<0.6	1.6	0.8**
		Pioneer 3517 Grain				
	1978	<0.6	0.7	0.7	2.5	1.1**
	1979	<0.6	<0.6	1.3	2.1	0.4**
	1980	<0.6	0.7	1.0	2.8	0.6**
		Pioneer 3541 Grain				
	1980	<0.6	<0.6	0.7	2.0	0.8**

(continued)

TABLE 10. (continued)

Constituent	Year	Sludge Treatment: 0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
		Pioneer 3517 Leaf				
Cr	1978	0.2	0.6	0.3	0.2	n.s.
	1979	0.9	0.9	1.0	1.0	n.s.
	1980	0.4	0.3	0.5	0.6	n.s.
		Pioneer 3541 Leaf				
	1980	<0.12	<0.12	0.26	0.38	0.23**
		Pioneer 3517 Stover				
	1978	0.8	0.7	1.0	1.1	n.s.
	1979	0.5	0.6	0.8	0.9	n.s.
	1980	0.2	0.3	0.4	0.2	n.s.
		Pioneer 3541 Stover				
	1980	0.15	<0.12	<0.12	0.17	n.s.
		Pioneer 3517 Grain				
	1978	0.30	0.30	<0.13	0.16	n.s.
	1979	<0.12	<0.12	0.13	0.17	n.s.
	1980	<0.12	<0.12	<0.12	0.16	n.s.
		Pioneer 3541 Grain				
	1980	<0.12	0.25	<0.12	0.34	n.s.

(continued)

TABLE 10. (continued)

Constituent	Year	Sludge Treatment: 0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
		Pioneer 3517 Leaf				
Pb	1978	1.4	1.8	1.6	1.6	n.s.
	1979	0.8	1.0	1.4	0.7	n.s.
	1980	0.7	0.7	0.6	0.7	n.s.
		Pioneer 3541 Leaf				
	1980	<0.62	<0.62	<0.62	0.66	n.s.
		Pioneer 3517 Stover				
	1978	1.5	1.6	1.4	1.2	n.s.
	1979	2.2	1.9	2.4	2.6	n.s.
	1980	2.7	1.8	2.4	1.7	n.s.
		Pioneer 3541 Stover				
	1980	1.52	1.26	1.69	1.30	n.s.
		Pioneer 3517 Grain				
	1978	<0.6	<0.6	<0.6	0.7	n.s.
	1979	<0.6	1.0	1.3	2.0	n.s.
	1980	<0.6	<0.9	<0.6	<0.6	n.s.
		Pioneer 3541 Grain				
	1980	<0.62	<0.62	0.70	<0.62	n.s.

n.s. = no significant differences.
*, ** = significant different at P_0.05 and P_0.01, respectively.

Methods and Materials

Details of this study were presented in a previous report (Hinesly and Hansen, 1981). The study was established in 1969 on a phosphorus deficient Blount silt loam soil as a split plot completely randomized block design with three replications of five treatments. One-half of the split plots received a broadcast application of 118 kg P/ha each year and the treatments on both plot halves were: 1) irrigation with maximum amounts of digested sewage sludge; 2) one-half maximum amounts of sludge; 3) one-fourth maximum amounts of sludge; 4) irrigation with well water in amounts equivalent to maximum sludge irrigation; and 5) no irrigation. Soybeans were planted each year on these plots from 1969 through 1976. In 1972, soybeans planted on plots treated with maximum amounts of digested sludge and broadcast applications of superphosphate suffered a severe P-toxicity. Thereafter sludge applications were terminated on split plots not previously treated with superphosphate, but were continued as before on the other half of each plot until the end of 1976. After soybeans were harvested in 1976, winter wheat was seeded each fall, but soybeans were planted again in 1978 after winter freezing and thawing had severely reduced wheat stands.

When sludge applications were terminated in 1972 on one-half of split plots and in 1976 on the other half, accumulative applications of sludge solids (dry weight basis) on maximum-treated plots amounted to 242 and 411 mt/ha, respectively.

Results and Discussion

An examination of data presented in Table 11 shows that previous sludge applications had increased concentrations of organic-C, N, and Ni in 0 to 15 cm depths of Blount and concentrations of P, Cd, Cu, Cr, Pb and Zn in 0 to 30 cm depths. In a comparison with those previously reported for 1977 (Hinesly and Hansen, 1981), these data showed small but significant decreases in concentrations of organic-C, N, P, Cd, Cr, Pb, and Zn in the 0 to 15 cm depth by maximum-sludge-treated Blount, but concentrations at deeper depths remained unchanged with time. Amounts of transition and heavy metals removed in soybeans and wheat can not account for losses nor is there any indication that they migrated to lower soil depths.

Soil pH was decreased by the two higher sludge loading rates, but it is unlikely that differences markedly affected the uptake of trace elements by soybeans and wheat.

Previous sludge applications had no effect on soybean and wheat grain yields (Table 12). Yields were about the same, regardless of when sludge applications had been terminated. But wheat stover yields were increased during the last year of the study where sludge was previously applied.

Of the several chemical element concentrations determined in soybean tissue (Table 13), those for Cd, Cu, Ni, and Zn were affected to the greatest extent by previous sludge applications. Concentrations of Cd, Ni, and Zn in soybean tissues from plots where sludge applications were terminated last had

TABLE 11. TOTAL CONTENTS OF SELECTED ELEMENTS AND pH DETERMINED IN 0 TO 15, 15 TO 30, 30 TO 46, AND 61 TO 76 cm SOIL DEPTH SAMPLES FROM BLOUNT SILT LOAM PLOTS PLANTED TO SOYBEANS AND WHEAT.a/b/

			Sludge Applications (1969-76)						Sludge Applications (1969-72)					
			Sludge and Water Treatments											
Parameter	Depth cm	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			%											
Organic-C	0-15	1978	0.93	1.17	1.34	1.80	2.12	0.52**	0.90	1.27	1.25	1.42	1.82	0.59**
		1979	0.93	1.18	1.42	1.77	2.29	0.58**	0.90	1.28	1.32	1.44	1.74	0.39*
		1980	0.93	1.15	1.37	1.69	2.09	0.62**	0.84	1.20	1.25	1.37	1.60	0.35*
	15-30	1978	0.66	1.15	1.13	1.19	1.27	n.s.	0.61	1.26	1.09	1.02	0.86	n.s.
		1979	0.76	1.10	1.06	1.25	1.23	n.s.	0.58	1.10	1.14	1.09	0.94	n.s.
		1980	0.65	1.02	1.03	1.16	1.09	n.s.	0.56	1.20	1.14	1.00	1.02	n.s.
	30-46	1978	0.38	0.74	0.47	0.50	0.48	n.s.	0.48	1.39	0.81	0.78	0.38	n.s.
		1979	0.37	0.68	0.44	0.51	0.39	n.s.	0.45	1.31	0.90	0.73	0.38	n.s.
	61-76	1978	0.38	0.32	0.40	0.39	0.36	n.s.	0.33	0.43	0.44	0.36	0.38	n.s.
		1979	0.36	0.30	0.33	0.33	0.34	n.s.	0.39	0.41	0.41	0.34	0.33	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
			Sludge and Water Treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			%											
N	0-15	1978	0.101	0.134	0.136	0.158	0.231	0.075**	0.098	0.122	0.126	0.137	0.184	0.051**
		1979	0.077	0.117	0.137	0.160	0.217	0.069**	0.083	0.123	0.127	0.137	0.163	0.042**
		1980	0.092	0.110	0.124	0.152	0.189	0.047**	0.092	0.105	0.115	0.128	0.148	0.029*
	15-30	1978	0.080	0.101	0.122	0.130	0.137	n.s.	0.079	0.127	0.111	0.134	0.102	n.s.
		1979	0.073	0.110	0.110	0.120	0.127	n.s.	0.077	0.123	0.110	0.110	0.103	n.s.
		1980	0.078	0.091	0.100	0.107	0.108	n.s.	0.069	0.113	0.107	0.101	0.111	n.s.
	30-46	1978	0.060	0.087	0.068	0.069	0.067	n.s.	0.068	0.143	0.093	0.096	0.059	n.s.
		1979	0.057	0.080	0.063	0.067	0.057	n.s.	0.063	0.110	0.097	0.080	0.060	n.s.
	61-76	1978	0.046	0.058	0.059	0.063	0.057	n.s.	0.048	0.072	0.066	0.062	0.057	0.014*
		1979	0.050	0.053	0.050	0.057	0.050	n.s.	0.053	0.063	0.063	0.050	0.043	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Applications (1969-76) Sludge and Water Treatments H_2O	0	1/4 Max	1/2 Max	Max	LSD	Sludge Applications (1969-72) H_2O	0	1/4 Max	1/2 Max	Max	LSD
			---mg/kg---											
P	0-15	1978	505	574	1016	1651	3178	430**	491	493	626	983	1908	404*
		1979	548	600	1180	1780	2970	359**	453	538	818	1210	1930	192**
		1980	499	546	1080	1910	2560	368**	503	559	981	1260	1790	499**
	15-30	1978	361	398	749	946	1227	535*	464	558	518	633	955	152*
		1979	426	506	765	1070	1250	564**	416	527	658	759	977	223**
		1980	436	453	685	922	1030	217**	441	484	635	633	903	266**
	30-46	1978	348	323	369	329	369	n.s.	367	508	440	406	353	n.s.
		1979	364	398	388	395	376	n.s.	451	571	479	436	409	n.s.
	61-76	1978	353	344	377	373	367	n.s.	322	463	370	323	343	n.s.
		1979	338	406	322	362	338	n.s.	336	412	382	392	309	n.s.

(continued)

TABLE 11. (continued)

Para-meter	Depth cm	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
			Sludge and Water Treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			-%											
K	0-15	1978	2.00	2.02	1.99	1.98	1.94	n.s.	2.07	2.01	2.05	1.99	1.97	n.s.
		1979	2.04	1.88	2.01	1.99	1.96	n.s.	2.06	2.02	2.15	2.00	2.03	n.s.
		1980	1.89	1.89	1.86	1.92	1.86	n.s.	2.00	1.90	1.92	1.88	1.90	n.s.
	15-30	1978	2.07	1.99	2.04	2.00	2.01	n.s.	1.97	1.96	2.16	1.97	1.94	n.s.
		1979	2.20	2.11	2.06	2.08	2.02	0.11*	2.24	2.09	2.19	2.04	2.19	n.s.
		1980	2.06	1.90	1.95	2.00	1.97	n.s.	2.28	1.89	1.93	1.95	2.05	0.27**
	30-46	1978	2.40	2.14	2.23	2.13	2.23	n.s.	2.49	2.08	2.25	2.10	2.13	n.s.
		1979	2.18	2.15	2.27	2.16	2.22	n.s.	2.59	2.19	2.38	1.98	2.28	0.334*
	61-76	1978	2.57	2.22	2.31	2.38	2.34	n.s.	2.10	2.16	2.26	2.91	2.27	n.s.
		1979	2.86	2.27	2.49	2.42	2.51	n.s.	2.60	2.25	2.43	2.49	2.01	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Applications (1969-76) — Sludge and Water Treatments: H_2O	0	1/4 Max	1/2 Max	Max	LSD	Sludge Applications (1969-72) — Sludge and Water Treatments: H_2O	0	1/4 Max	1/2 Max	Max	LSD
			%											
Na	0-15	1978	0.836	0.872	0.837	0.828	0.791	n.s.	0.774	0.864	0.837	0.841	0.792	n.s.
		1979	0.778	0.767	0.808	0.782	0.752	n.s.	0.706	0.807	0.828	0.787	0.762	n.s.
		1980	0.812	0.879	0.839	0.840	0.797	0.047*	0.780	0.857	0.824	0.830	0.779	n.s.
	15-30	1978	0.674	0.861	0.816	0.797	0.756	0.106*	0.535	0.799	0.797	0.816	0.663	n.s.
		1979	0.721	0.828	0.774	0.770	0.717	0.075*	0.694	0.828	0.753	0.758	0.709	n.s.
		1980	0.731	0.827	0.794	0.747	0.758	n.s.	0.608	0.842	0.821	0.805	0.731	0.139**
	30-46	1978	0.631	0.864	0.773	0.748	0.702	n.s.	0.574	0.852	0.745	0.771	0.759	n.s.
		1979	0.524	0.764	0.681	0.686	0.628	n.s.	0.475	0.791	0.664	0.628	0.524	n.s.
	61-76	1978	0.515	0.712	0.576	0.571	0.562	n.s.	0.374	0.736	0.522	0.832	0.539	n.s.
		1979	0.495	0.709	0.611	0.587	0.485	n.s.	0.416	0.715	0.574	0.650	0.421	0.207*

(continued)

TABLE 11. (continued)

Para-meter	Depth cm	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
			Sludge and Water Treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			%											
Ca	0-15	1978	0.449	0.463	0.516	0.544	0.599	0.072**	0.487	0.451	0.517	0.518	0.745	0.200**
		1979	0.366	0.406	0.425	0.470	0.525	0.098**	0.456	0.402	0.470	0.461	0.516	n.s.
		1980	0.489	0.432	0.500	0.489	0.570	n.s.	0.411	0.457	0.478	0.506	0.542	0.040**
	15-30	1978	0.406	0.445	0.463	0.491	0.542	n.s.	0.346	0.457	0.466	0.472	0.415	n.s.
		1979	0.414	0.452	0.498	0.507	0.493	0.062*	0.420	0.461	0.493	0.516	0.516	n.s.
		1980	0.422	0.399	0.409	0.417	0.424	n.s.	0.381	0.415	0.433	0.410	0.422	n.s.
	30-46	1978	0.391	0.399	0.385	0.420	0.409	n.s.	0.586	0.487	0.443	0.411	0.426	n.s.
		1979	0.420	0.393	0.452	0.347	0.370	n.s.	0.630	0.406	0.455	0.321	0.412	0.148*
	61-76	1978	1.52	0.394	1.08	0.490	1.25	n.s.	2.94	0.466	0.959	0.414	1.55	n.s.
		1979	1.22	0.455	1.14	0.598	1.22	n.s.	2.73	0.425	1.06	0.471	2.03	n.s.

(continued)

TABLE 11. (continued)

Para-meter	Depth cm	Year	Sludge Applications (1969-76) — Sludge and Water Treatments: H_2O	0	1/4 Max	1/2 Max	Max	LSD	Sludge Applications (1969-72) — Sludge and Water Treatments: H_2O	0	1/4 Max	1/2 Max	Max	LSD
			%											
Mg	0-15	1978	0.391	0.366	0.384	0.410	0.448	n.s.	0.495	0.369	0.441	0.415	0.640	n.s.
		1979	0.342	0.330	0.359	0.355	0.388	n.s.	0.433	0.334	0.380	0.382	0.405	n.s.
		1980	0.437	0.374	0.404	0.417	0.452	n.s.	0.511	0.389	0.431	0.428	0.468	n.s.
	15-30	1978	0.496	0.360	0.424	0.448	0.526	n.s.	0.464	0.343	0.456	0.419	0.433	n.s.
		1979	0.538	0.333	0.370	0.389	0.466	n.s.	0.604	0.344	0.421	0.407	0.497	0.151*
		1980	0.604	0.387	0.467	0.557	0.549	0.121*	0.778	0.379	0.410	0.463	0.561	0.275**
	30-46	1978	0.729	0.444	0.565	0.633	0.705	n.s.	0.938	0.461	0.548	0.585	0.605	n.s.
		1979	0.677	0.418	0.528	0.518	0.615	n.s.	0.814	0.382	0.520	0.507	0.568	n.s.
	61-76	1978	1.15	0.629	0.957	0.737	0.921	n.s.	1.52	0.582	0.841	0.686	1.29	n.s.
		1979	1.10	0.533	1.00	0.851	0.979	n.s.	1.31	0.563	0.983	0.726	1.18	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Applications (1969-76) H_2O	0	1/4 Max	1/2 Max	Max	LSD	Sludge Applications (1969-72) H_2O	0	1/4 Max	1/2 Max	Max	LSD
			Sludge and Water Treatments											
			%											
Fe	0-15	1978	1.91	1.80	2.00	2.31	2.56	0.50**	2.34	1.96	2.20	2.10	2.41	n.s.
		1979	2.07	1.83	2.04	2.13	2.35	0.31*	2.48	1.84	2.30	2.06	2.40	n.s.
		1980	2.18	1.77	2.04	2.03	2.21	n.s.	2.49	1.95	2.10	2.01	2.38	n.s.
	15-30	1978	3.01	1.92	2.32	2.38	2.66	n.s.	3.46	1.97	2.62	2.24	2.80	n.s.
		1979	2.83	1.91	2.21	2.21	2.50	n.s.	3.44	1.98	2.52	2.22	2.80	0.78*
		1980	2.96	1.77	2.45	2.15	2.60	n.s.	3.72	1.76	2.37	2.10	3.04	1.12*
	30-46	1978	4.18	2.18	3.14	3.12	3.65	n.s.	4.28	2.26	3.15	2.99	2.95	n.s.
		1979	3.94	2.42	3.07	3.41	3.78	n.s.	4.44	2.28	3.07	2.77	3.93	n.s.
	61-76	1978	4.09	3.49	4.02	4.53	3.99	n.s.	3.21	3.46	3.70	4.80	3.76	n.s.
		1979	4.26	3.26	4.26	4.18	4.02	n.s.	3.92	3.37	3.84	4.02	3.24	n.s.

(continued)

TABLE 11. (continued)

Para-meter	Depth cm	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
			Sludge and Water Treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			mg/kg											
Mn	0-15	1978	1180	1630	1510	1640	1360	n.s.	1200	1580	1430	1200	1420	n.s.
		1979	1120	1210	1310	1140	1060	n.s.	953	1200	1200	1040	1040	n.s.
		1980	1220	1100	1260	1190	1070	n.s.	1020	1220	1190	1130	1050	n.s.
	15-30	1978	944	1330	1300	1410	984	n.s.	783	1740	1360	1190	888	n.s.
		1979	721	1240	1200	980	758	n.s.	659	1420	1380	829	803	n.s.
		1980	865	1060	1160	1020	802	n.s.	669	1240	1320	863	884	n.s.
	30-46	1978	544	935	829	793	698	n.s.	612	1810	1200	1060	805	n.s.
		1979	422	793	621	594	672	n.s.	602	1390	1110	737	485	n.s.
	61-76	1978	681	447	465	604	504	n.s.	520	1190	531	518	554	446*
		1979	640	429	473	597	483	n.s.	617	742	640	714	476	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
			Sludge and Water Treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			mg/kg											
Zn	0-15	1978	62	68	152	275	448	59**	70	66	114	189	340	62**
		1979	67	76	156	255	409	29**	70	77	125	190	308	29**
		1980	70	71	157	255	382	48**	70	77	126	187	295	29**
	15-30	1978	83	61	135	181	226	101**	82	83	108	143	175	27**
		1979	71	69	108	174	213	58**	79	74	103	132	192	20**
		1980	78	67	111	155	186	31**	92	73	105	116	167	23**
	30-46	1978	98	75	88	99	118	n.s.	106	80	91	97	101	n.s.
		1979	87	52	71	91	99	n.s.	83	64	78	73	97	15**
	61-76	1978	99	92	101	109	99	n.s.	96	100	103	103	102	n.s.
		1979	106	83	108	107	102	14*	95	89	105	100	82	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Applications (1969-76), Sludge and Water Treatments: H_2O	0	1/4 Max	1/2 Max	Max	LSD	Sludge Applications (1969-72), Sludge and Water Treatments: H_2O	0	1/4 Max	1/2 Max	Max	LSD
			mg/kg											
Cd	0-15	1978	0.43	0.97	5.09	12.12	22.72	3.80**	0.51	0.84	3.21	7.14	15.93	3.70**
		1979	<0.25	0.85	5.28	10.7	20.9	1.92**	<0.25	0.67	4.48	7.09	12.6	3.45**
		1980	<0.25	0.56	5.17	10.8	17.5	2.96**	<0.25	0.68	3.00	6.87	12.6	1.62**
	15-30	1978	<0.25	<0.25	3.19	6.06	9.08	6.85**	<0.25	<0.25	1.85	3.94	5.64	1.13**
		1979	<0.25	<0.25	2.42	5.88	8.68	3.00**	<0.25	0.46	1.65	3.61	6.16	1.44**
		1980	<0.25	<0.25	1.78	4.25	5.99	0.91**	<0.25	0.28	2.61	2.69	4.88	2.45**
	30-46	1978	<0.25	<0.25	0.34	0.36	0.68	n.s.	<0.25	<0.25	<0.25	0.32	0.36	n.s.
		1979	<0.25	<0.25	<0.25	0.33	0.54	0.28*	<0.25	<0.25	0.26	0.17	0.49	n.s.
	61-76	1978	<0.25	<0.25	<0.25	<0.25	<0.25	n.s.	<0.25	<0.25	<0.25	<0.25	<0.25	n.s.
		1979	<0.25	<0.25	<0.25	<0.25	<0.25	n.s.	<0.25	<0.25	<0.25	<0.25	<0.25	n.s.

(continued)

TABLE 11. (continued)

Para- meter	Depth cm	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
			Sludge and Water Treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			-mg/kg-											
Cu	0-15	1978	18	19	46	87	148	22**	18	18	34	56	102	14*
		1979	22	21	52	86	154	16**	23	22	39	62	100	11**
		1980	18	19	47	81	129	19**	21	21	33	54	93	10**
	15-30	1978	28	19	44	57	78	29**	27	20	33	41	55	9**
		1979	20	26	35	51	67	22**	25	22	31	35	56	5**
		1980	18	12	27	39	52	10**	25	14	25	26	47	7**
	30-46	1978	31	20	31	29	29	n.s.	36	20	27	26	24	n.s.
		1979	29	18	22	21	25	n.s.	34	18	22	21	31	11*
	61-76	1978	34	28	31	35	29	n.s.	33	30	31	31	31	n.s.
		1979	35	27	33	32	26	n.s.	34	23	29	34	27	n.s.

(continued)

TABLE 11. (continued)

Para-meter	Depth cm	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
			Sludge and Water Treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			mg/kg											
Ni	0-15	1978	18	16	23	26	38	4**	18	19	17	21	24	n.s.
		1979	13	13	19	24	36	5**	15	13	15	18	25	4**
		1980	28	25	33	39	50	4**	31	27	31	34	42	6**
	15-30	1978	28	23	28	30	34	n.s.	28	27	26	25	31	n.s.
		1979	22	19	22	25	29	6*	30	22	24	21	28	n.s.
		1980	27	23	28	29	32	n.s.	35	21	27	25	33	9**
	30-46	1978	36	22	29	25	32	n.s.	47	30	33	28	29	n.s.
		1979	30	20	26	24	28	n.s.	44	26	33	26	36	13**
	61-76	1978	42	28	33	38	37	n.s.	41	29	37	38	40	n.s.
		1979	40	20	28	30	34	n.s.	36	22	30	34	29	n.s.

(continued)

TABLE 11. (continued)

			Sludge Applications (1969-76)						Sludge Applications (1969-72)					
			Sludge and Water Treatments											
Parameter	Depth cm	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			mg/kg											
Cr	0-15	1978	43	46	119	202	354	31**	47	44	71	116	199	29**
		1979	36	38	95	141	232	29**	38	37	66	105	167	14**
		1980	43	32	86	146	261	40**	45	57	72	114	195	55**
	15-30	1978	49	43	76	96	126	41**	51	38	59	76	90	14**
		1979	43	37	59	95	117	30**	49	37	56	73	100	14**
		1980	30	23	40	53	68	14**	36	24	44	43	64	12**
	30-46	1978	58	40	51	54	56	n.s.	63	39	50	48	57	12*
		1979	56	36	50	48	47	n.s.	56	36	49	45	67	n.s.
	61-76	1978	58	43	60	49	55	n.s.	70	50	65	52	68	n.s.
		1979	62	51	72	60	52	14*	60	52	57	55	48	n.s.

(continued)

TABLE 11. (continued)

Para- meter	Depth cm	Year	Sludge Applications (1969-76): H_2O	0	1/4 Max	1/2 Max	Max	LSD	Sludge Applications (1969-72): H_2O	0	1/4 Max	1/2 Max	Max	LSD
			Sludge and Water Treatments (mg/kg)											
Pb	0-15	1978	25	24	42	68	111	23**	22	21	35	50	89	26**
		1979	23	23	46	67	107	8**	23	24	37	53	82	6**
		1980	22	26	46	72	101	15**	23	32	39	55	84	15**
	15-30	1978	31	30	48	58	68	25**	30	30	38	47	50	10**
		1979	23	28	36	39	53	15*	23	24	38	37	48	12**
		1980	18	20	26	32	39	10**	20	18	31	26	39	8**
	30-46	1978	18	15	17	19	18	n.s.	20	16	17	17	16	n.s.
		1979	21	17	19	19	19	n.s.	22	18	18	18	20	n.s.
	61-76	1978	23	17	18	25	22	n.s.	19	19	18	25	20	n.s.
		1979	20	18	19	19	22	n.s.	18	15	18	20	18	n.s.

(continued)

TABLE 11. (continued)

Parameter	Depth cm	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
			Sludge and Water Treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			Units											
pH	0-15	1978	6.3	6.1	5.6	5.5	5.1	0.8**	6.2	6.1	6.3	6.0	5.8	n.s.
		1979	6.7	6.6	6.4	6.1	5.9	0.4**	6.8	6.6	6.6	6.4	6.3	n.s.
		1980	6.7	6.6	6.4	6.1	6.0	0.4*	6.7	6.6	6.6	6.5	6.4	n.s.
	15-30	1978	5.2	5.4	5.2	5.0	4.6	0.4*	5.4	5.8	5.7	5.5	5.2	n.s.
		1979	5.3	5.8	5.6	5.4	5.0	0.5*	5.6	5.7	5.7	5.5	5.3	n.s.
		1980	5.6	5.8	5.5	5.3	5.1	0.4*	5.5	5.9	5.9	5.4	5.5	0.4**
	30-46	1978	4.8	4.6	4.6	4.4	4.3	0.2*	5.9	4.7	5.1	4.6	4.7	0.9*
		1979	5.2	5.0	4.8	4.8	4.5	n.s.	6.1	5.1	5.4	4.8	5.0	n.s.
	61-76	1978	6.1	4.5	5.7	5.2	5.3	n.s.	7.0	4.6	5.5	5.3	6.3	n.s.
		1979	6.4	4.8	5.7	5.5	5.7	n.s.	7.1	5.0	5.9	5.5	6.5	n.s.

a/ Concentrations are on a dry-weight basis.
b/ After 1973, P applications were terminated and sludge applications were continued after 1972 only on split-plots formerly treated with superphosphate.
*,** Significantly different at P<0.05 and P<0.01, respectively.

TABLE 12. SOYBEAN YIELDS AND WHEAT GRAIN AND STOVER YIELDS FROM PLOTS DESIGNATED NW 500.

	Continued Sludge Applications						Terminated Sludge Applications					
	Sludge Application Rates											
Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
	Soybean Bean Yield											
	mt/ha (13.0% moisture)											
1978	1.16	1.59	1.59	1.69	1.63	n.s.	1.05	1.50	1.38	1.87	1.65	n.s.
	Wheat Grain Yield											
	mt/ha (13.5% moisture)											
1979	3.5	3.4	4.7	4.6	4.0	n.s.	2.7	3.3	3.9	4.6	4.8	n.s.
1980	1.79	2.40	3.77	2.73	3.44	n.s.	1.37	2.21	2.98	2.59	3.82	n.s.
	Wheat Stover Yield											
	mt/ha (dry weight)											
1979	3.57	3.60	5.00	4.83	4.83	n.s.	2.83	3.50	4.10	5.63	5.10	n.s.
1980	2.17	3.59	6.25	6.68	7.95	2.84**	1.53	3.95	3.71	3.79	6.48	7.12*

*, ** = significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = no significant differences.

higher concentrations than those from plots which received sludge for a shorter time. But Cu concentrations were not significantly different between the two sludge application periods. Copper concentrations in leaf and petiole and beans were significantly less on plots treated with maximum amounts of sludge as compared to similar tissues from control plots. Relative to concentrations previously reported (Hinesly and Hansen, 1981), Ni, Cd, and Zn decreased most rapidly in all soybean tissues after sludge applications were terminated by order of listing. Bean-Zn concentrations did not decrease after sludge applications were terminated. Six years after sludge applications were suspended, both Zn and Cd concentrations remained at significantly higher levels in beans from sludge-treated Blount as compared to those from control plots.

Cadmium, Cu, Ni, and Zn were the elements whose concentrations in wheat grain and residues were most enhanced by sludge applications. In comparing the concentrations of these elements in wheat tissues collected during the last year of the study with those three years earlier, as reported by Hinesly and Hansen (1981), for the same variety, it appears that concentrations of Ni and Cu receded very rapidly toward background levels after sludge applications were terminated. This was not the case for Cd and Zn concentrations. These two elements were readily available for uptake by wheat eight years after sludge applications were suspended.

Summary and Conclusion

After the second year following the suspension of sludge applications, organic matter contents of sludge amended Blount did not change significantly. Concentrations of Cd, Ni, and Zn soybean tissues decreased precipitously the first year or two after sludge applications were suspended, but very little after that time. Concentrations of Cd and Zn in wheat tissues from plots formerly treated with sludge did not decrease with time, but Ni and Cu concentrations did.

Nickel concentrations were higher in the bean of soybeans and grain of wheat than in foliage tissues. Concentrations of Cu were decreased in soybeans and increased in wheat as a result of sludge applications.

If the uptake of transition and heavy metals by soybeans and wheat were a problem, there is no indication that the situation worsened after termination of sludge applications.

Further work is needed to see if Cd uptake by wheat could be reduced by liming the sludge-amended Blount soil.

RESPONSES OF CONTINUOUS CORN ON STRIP-MINE SPOIL WITH AND WITHOUT ANNUAL APPLICATIONS OF DIGESTED SEWAGE SLUDGE

Introduction

Strip-mined lands have low contents of organic matter. Nitrogen levels are too low in freshly graded spoil to support nonleguminous plants. In

TABLE 13. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS OF LEAF AND PETIOLE, BEAN, AND STALK SAMPLES FROM SOYBEANS (BEESON CULTIVAR) AND LEAF, GRAIN, AND STOVER SAMPLES FROM WHEAT (ABE VARIETY) GROWN ON BLOUNT SILT LOAM SOIL, WITH AND WITHOUT SLUDGE.[a]

		Sludge Applications (1969-76)						Sludge Applications (1969-72)					
		Sludge and Water Treatments											
Constituent	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		%											
		Soybean leaf and petiole											
N	1978	3.39	3.58	3.73	3.02	2.72	0.54**	2.87	3.60	3.23	3.00	2.72	n.s.
		Soybean bean											
	1978	6.44	6.59	6.46	6.78	6.45	n.s.	6.56	6.25	6.58	6.49	6.48	n.s.
		Soybean plant residue											
	1978	0.76	0.88	0.82	0.75	0.60	n.s.	0.99	0.75	0.84	0.83	0.69	n.s.
		Wheat leaf											
	1980	2.17	2.41	3.34	3.55	3.97	0.54**	2.32	2.59	2.45	2.64	3.13	0.33**
		Wheat grain											
	1979	1.89	2.03	2.47	2.52	2.81	0.51**	1.71	2.12	1.95	2.20	2.30	n.s.
	1980	1.70	1.84	2.33	2.42	2.60	0.41**	1.72	2.02	1.76	1.86	2.13	0.26*
		Wheat stover											
	1979	0.225	0.210	0.333	0.427	0.604	0.239**	0.226	0.210	0.222	0.263	0.315	0.043**
	1980	0.254	0.234	0.278	0.402	0.524	0.175**	0.235	0.255	0.215	0.239	0.243	n.s.

(continued)

TABLE 13. (continued)

Constituent	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
		Sludge and Water Treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		%											
		Soybean leaf and petiole											
P	1978	0.194	0.232	0.191	0.095	0.136	0.069*	0.129	0.219	0.192	0.117	0.126	0.076*
		Soybean bean											
	1978	0.512	0.553	0.488	0.408	0.514	n.s.	0.467	0.507	0.513	0.505	0.499	n.s.
		Soybean plant residue											
	1978	0.062	0.067	0.053	0.037	0.056	n.s.	0.044	0.056	0.048	0.044	0.038	n.s.
		Wheat leaf											
	1980	0.363	0.362	0.470	0.576	0.599	0.052**	0.279	0.266	0.395	0.434	0.562	0.200**
		Wheat grain											
	1979	0.399	0.417	0.480	0.489	0.491	0.057**	0.359	0.436	0.457	0.471	0.482	0.072*
	1980	0.438	0.443	0.485	0.472	0.484	n.s.	0.462	0.459	0.448	0.447	0.440	n.s.
		Wheat stover											
	1979	0.020	0.036	0.081	0.078	0.141	0.069*	0.020	0.032	0.044	0.051	0.062	0.020**
	1980	0.049	0.065	0.080	0.132	0.182	0.064**	0.044	0.046	0.062	0.071	0.080	0.022**

(continued)

TABLE 13. (continued)

Constituent	Year	Sludge Applications (1969-76) — Sludge and Water Treatments: H_2O	0	1/4 Max	1/2 Max	Max	LSD	Sludge Applications (1969-72) — Sludge and Water Treatments: H_2O	0	1/4 Max	1/2 Max	Max	LSD
		%											
		Soybean leaf and petiole											
Ca	1978	1.85	2.03	2.04	2.48	2.60	0.37 **	1.85	2.12	1.85	2.02	2.13	n.s.
		Soybean bean											
	1978	0.236	0.219	0.188	0.172	0.162	0.030**	0.224	0.226	0.219	0.199	0.177	0.028**
		Soybean plant residue											
	1978	0.889	0.942	0.813	0.916	0.792	n.s.	0.808	0.935	0.891	0.800	0.798	n.s.
		Wheat leaf											
	1980	0.348	0.360	0.426	0.547	0.711	0.217**	0.342	0.275	0.324	0.348	0.499	n.s.
		Wheat grain											
	1979	0.024	0.025	0.030	0.034	0.036	0.007**	0.022	0.026	0.024	0.027	0.032	0.004**
	1980	0.024	0.025	0.026	0.029	0.032	n.s.	0.024	0.023	0.023	0.025	0.026	0.002*
		Wheat stover											
	1979	0.151	0.156	0.182	0.268	0.280	0.067**	0.156	0.146	0.166	0.159	0.224	0.043**
	1980	0.116	0.115	0.138	0.149	0.144	n.s.	0.116	0.114	0.113	0.118	0.127	n.s.

(continued)

TABLE 13. (continued)

Constituent	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
		Sludge and Water Treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		%											
		Soybean leaf and petiole											
Mg	1978	0.480	0.468	0.560	0.642	1.32	0.524*	0.423	0.436	0.432	0.461	0.542	n.s.
		Soybean bean											
	1978	0.224	0.243	0.240	0.246	0.261	0.016**	0.209	0.251	0.238	0.245	0.228	0.028**
		Soybean plant residue											
	1978	0.512	0.476	0.477	0.462	0.398	n.s.	0.454	0.468	0.476	0.449	0.450	n.s.
		Wheat leaf											
	1980	0.241	0.222	0.249	0.396	0.447	0.050**	0.231	0.174	0.224	0.227	0.285	n.s.
		Wheat grain											
	1979	0.159	0.162	0.183	0.184	0.176	0.017*	0.134	0.163	0.170	0.165	0.179	0.022*
	1980	0.165	0.164	0.179	0.173	0.174	n.s.	0.170	0.171	0.166	0.170	0.163	n.s.
		Wheat stover											
	1979	0.097	0.106	0.111	0.132	0.165	0.034*	0.128	0.109	0.104	0.101	0.115	n.s.
	1980	0.124	0.117	0.098	0.104	0.111	n.s.	0.131	0.112	0.114	0.109	0.094	n.s.

(continued)

TABLE 13. (continued)

Constituent	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
		Sludge and Water Treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		mg/kg											
		Soybean leaf and petiole											
Fe	1978	114	122	102	93	88	19*	90	110	110	94	90	14**
		Soybean bean											
	1978	148	74	73	63	60	n.s.	148	79	79	76	82	44*
		Soybean plant residue											
	1978	255	205	246	267	232	n.s.	146	229	214	222	233	n.s.
		Wheat leaf											
	1980	146	118	108	155	136	n.s.	179	118	114	165	126	n.s.
		Wheat grain											
	1979	52.0	57.2	64.9	59.7	62.3	n.s.	44.3	59.7	59.7	62.3	57.1	9.95*
	1980	46.6	56.5	56.3	56.8	72.8	n.s.	44.4	48.4	49.8	42.3	49.4	n.s.
		Wheat stover											
	1979	85.4	95.9	90.6	159	135	n.s.	120	88.1	109	101	122	n.s.
	1980	120	107	106	93.0	96.4	n.s.	165	97.7	95.1	93.6	99.2	51.3**

(continued)

TABLE 13. (continued)

Constituent	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
		Sludge and Water Treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		mg/kg											
		Soybean leaf and petiole											
Mn	1978	84	109	100	108	212	82*	59	110	86	83	84	n.s.
		Soybean bean											
	1978	34	31	26	24	29	n.s.	24	28	26	24	26	n.s.
		Soybean plant residue											
	1978	35	44	35	43	48	n.s.	24	46	36	34	34	12*
		Wheat leaf											
	1980	127	116	105	113	100	n.s.	90.4	92.7	115	101	87.0	n.s.
		Wheat grain											
	1979	28.2	29.8	29.4	31.7	23.7	n.s.	24.7	33.9	31.4	29.4	23.4	n.s.
	1980	46.8	46.8	51.8	42.5	31.9	13.4**	39.7	48.2	51.8	46.1	36.9	n.s.
		Wheat stover											
	1979	64.3	65.6	57.2	68.4	60.0	n.s.	52.6	74.5	69.3	54.4	50.2	n.s.
	1980	76.6	72.3	55.3	52.5	34.8	26.2**	60.3	67.3	68.1	61.0	36.2	20.4*

(continued)

TABLE 13. (continued)

Constituent	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
		Sludge and Water Treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		mg/kg											
		Soybean leaf and petiole											
Zn	1978	30	41	113	168	262	34**	28	40	65	106	129	30**
		Soybean bean											
	1978	52	57	77	82	93	16**	49	56	62	74	76	9**
		Soybean plant residue											
	1978	12	12	31	66	117	33**	11	15	19	33	40	14**
		Wheat leaf											
	1980	9.11	10.3	28.8	74.9	108	35.8**	7.88	9.05	15.4	32.6	75.5	12.5**
		Wheat grain											
	1979	36.5	44.5	87.8	99.2	113	27.1**	31.5	51.8	60.5	85.1	94.9	18.1**
	1980	34.8	38.7	79.7	91.4	99.7	25.3**	34.6	43.3	49.5	66.8	90.6	19.4**
		Wheat stover											
	1979	6.77	16.2	111	217	261	121**	12.6	22.1	50.3	141	206	93.4**
	1980	13.0	13.5	62.5	155	196	51.9**	12.1	14.6	31.4	74.7	152	59.5**

(continued)

TABLE 13. (continued)

Constituent	Year	Sludge Applications (1969-76) H_2O	0	1/4 Max	1/2 Max	Max	LSD	Sludge Applications (1969-72) H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Sludge and Water Treatments											
		mg/kg											
		Soybean leaf and petiole											
Cd	1978	0.07	0.17	1.50	2.52	8.31	0.94**	<0.06	0.17	0.57	1.63	2.45	0.51**
		Soybean bean											
	1978	0.13	0.18	0.39	0.60	1.30	0.32**	0.09	0.13	0.29	0.50	0.49	0.22**
		Soybean plant residue											
	1978	0.11	0.22	0.85	1.78	3.96	1.26**	0.09	0.20	0.55	1.28	1.40	0.40**
		Wheat leaf											
	1980	0.072	0.143	1.10	4.08	7.54	1.07**	<0.06	0.121	0.600	1.56	3.90	1.83**
		Wheat grain											
	1979	0.117	0.185	1.35	2.41	3.10	0.354**	0.100	0.176	0.635	1.64	2.66	0.901**
	1980	0.075	0.122	1.31	2.93	4.29	0.721**	<0.06	0.092	0.567	1.31	3.46	1.60**
		Wheat stover											
	1979	0.152	0.262	1.83	5.23	8.81	3.76**	0.165	0.335	0.952	3.10	5.22	2.00**
	1980	0.204	0.231	1.94	6.22	9.62	2.76**	0.222	0.237	0.761	2.38	7.11	3.29**

(continued)

TABLE 13. (continued)

Constit-uent	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
		Sludge and Water Treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		mg/kg											
		Soybean leaf and petiole											
Cu	1978	5.2	6.5	6.0	4.2	4.2	0.8**	5.4	6.6	5.9	5.1	4.4	0.8**
		Soybean bean											
	1978	12.6	14.0	14.1	11.1	12.2	n.s.	16.7	15.1	13.5	12.6	12.4	2.6*
		Soybean plant residue											
	1978	2.6	2.7	2.5	2.6	3.1	n.s.	3.4	3.1	2.6	2.6	3.0	n.s.
		Wheat leaf											
	1980	5.73	5.24	6.93	8.69	8.77	2.45*	4.91	4.40	5.66	5.74	7.76	1.90*
		Wheat grain											
	1979	4.56	3.98	5.02	4.96	5.76	0.808*	4.04	4.38	4.67	4.84	5.47	n.s.
	1980	3.55	3.48	4.41	4.26	4.72	0.654**	3.69	3.91	3.82	3.98	4.30	n.s.
		Wheat stover											
	1979	2.84	2.20	2.43	2.60	5.12	n.s.	1.90	1.73	2.02	2.55	3.13	0.714*
	1980	1.35	1.28	2.18	2.45	3.48	1.13**	1.24	1.38	1.43	1.43	1.92	n.s.

(continued)

TABLE 13. (continued)

Constituent	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
		Sludge and Water Treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		mg/kg											
		Soybean leaf and petiole											
Ni	1978	0.7	0.6	1.2	1.1	2.4	1.0**	0.6	1.0	1.0	1.0	0.8	n.s.
		Soybean bean											
	1978	4.4	5.3	6.2	8.9	16.2	4.2**	3.9	5.8	5.2	5.6	6.4	n.s.
		Soybean plant residue											
	1978	<0.6	<0.6	0.8	1.3	3.4	1.3**	<0.6	0.7	0.6	0.9	0.8	0.4*
		Wheat leaf											
	1980	<0.62	<0.62	<0.62	0.698	<0.62	n.s.	<0.62	<0.62	<0.62	<0.62	<0.62	n.s.
		Wheat grain											
	1979	0.689	0.661	1.13	1.77	3.32	1.13**	<0.62	0.709	0.832	1.72	1.54	0.862*
	1980	<0.62	<0.62	<0.62	<0.62	1.84	0.629**	<0.62	<0.62	<0.62	<0.62	<0.62	n.s.
		Wheat stover											
	1979	0.859	1.30	0.661	1.10	2.51	1.14*	<0.62	0.803	0.724	1.39	1.17	n.s.
	1980	<0.62	0.878	<0.62	<0.62	1.14	n.s.	<0.62	<0.62	<0.62	<0.62	<0.62	n.s.

(continued)

TABLE 13. (continued)

Constit-uent	Year	Sludge Applications (1969-76)						Sludge Applications (1969-72)					
		Sludge and Water Treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		mg/kg											
		Soybean leaf and petiole											
Cr	1978	0.28	0.14	0.37	0.14	0.30	n.s.	0.28	0.40	0.54	0.71	0.61	n.s.
		Soybean bean											
	1978	1.46	0.75	0.82	1.04	1.39	n.s.	1.36	0.94	1.24	2.15	1.90	n.s.
		Soybean plant residue											
	1978	1.2	1.4	1.5	2.1	1.5	n.s.	1.0	1.5	1.4	0.9	2.1	n.s.
		Wheat leaf											
	1980	1.30	1.56	0.962	1.36	1.27	n.s.	0.777	1.15	1.57	1.25	1.84	n.s.
		Wheat grain											
	1979	0.514	0.455	0.588	0.383	0.475	n.s.	0.573	0.463	0.576	0.774	0.537	n.s.
	1980	<0.125	<0.125	<0.125	<0.125	0.283	n.s.	0.235	0.133	0.178	0.524	<0.125	n.s.
		Wheat stover											
	1979	<0.125	0.199	0.230	0.276	0.293	n.s.	0.901	<0.125	0.358	0.290	0.191	n.s.
	1980	0.851	1.34	1.03	1.18	2.69	n.s.	0.533	0.534	0.728	0.679	1.26	n.s.

(continued)

TABLE 13. (continued)

Constituent	Year	Sludge Applications (1969-76): H_2O	0	1/4 Max	1/2 Max	Max	LSD	Sludge Applications (1969-72): H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Sludge and Water Treatments											
		mg/kg											
		Soybean leaf and petiole											
Pb	1978	2.4	2.0	2.0	2.0	1.8	n.s.	2.5	1.8	2.6	2.3	2.4	n.s.
		Soybean bean											
	1978	<0.6	0.8	<0.6	<0.6	<0.6	n.s.	1.0	1.3	<0.6	<0.6	<0.6	n.s.
		Soybean plant residue											
	1978	1.3	1.2	1.5	1.6	1.5	n.s.	1.0	1.3	1.5	1.6	1.8	n.s.
		Wheat leaf											
	1980	1.50	1.19	1.03	1.42	2.23	n.s.	0.859	0.747	1.02	1.22	1.81	n.s.
		Wheat grain											
	1979	<0.62	<0.62	<0.62	<0.62	<0.62	n.s.	<0.62	<0.62	<0.62	0.805	<0.62	n.s.
	1980	<0.62	<0.62	<0.62	<0.62	<0.62	n.s.	<0.62	<0.62	<0.62	<0.62	<0.62	n.s.
		Wheat stover											
	1979	1.40	<0.62	1.59	1.11	1.01	n.s.	0.832	<0.62	0.721	0.795	1.05	0.248**
	1980	<0.62	<0.62	<0.62	<0.62	<0.62	n.s.	<0.62	<0.62	<0.62	<0.62	<0.62	n.s.

a/ Concentrations are on a dry-weight basis.
*,** Significantly different at P<0.05 and P<0.01, respectively.

calcareous strip-mine spoil P availability is low and the growth of many plant species are restricted because they are unable to obtain sufficient amounts of this major nutrient. But strip-mined lands frequently contain abundant quantities of available K. Digested sewage sludges contain 40 to 50% organic matter, and, if applied at sufficiently high loading rates, can supply ample amounts of N and P for plant growth. Thus, it seemed reasonable to expect that applications of sewage sludge would improve soil physical properties, provide N and P for balanced plant nutrition with the K present in strip-mine spoil, and the high pH of calcareous spoil would minimize the uptake of transition and heavy metals contained in sewage sludge.

A cooperative study with the Metropolitan Sanitary District of Chicago was initiated in 1973 on freshly graded strip-mined spoil in Fulton County, Illinois to determine the responses of corn to sewage sludge annually applied by furrow irrigation. The results obtained through 1977 from this study were reported previously (Hinesly and Hansen, 1981). Funding to the Department of Agronomy, University of Illinois, to support the continuation of this study ended in 1979. Thus, the purpose here is to report findings for the two additional years of the study.

Materials and Methods

The protocol for the calcareous strip-mine spoil study was the same as that for the long-term continuous corn study initiated on acid Blount silt loam in 1968 on the Northeast Agronomy Research Center, which was discussed earlier in section 4 of this report.

Results and Discussion

Concentrations of selected chemical elements in sludge are shown in Tables 14 and 15. At the end of the last growing season, 392 mt/ha (dry weight equivalent) of sludge solids had been applied on maximum sludge-treated plots of strip-mine spoil material. A total of 248 mt/ha had been applied prior to 1978. Appropriately lesser amounts were applied on 1/4- and 1/2-maximum-treated plots. Maximum sludge loading rates supplied more than 3,000 and 2,000 kg/ha of N and P, respectively, during each of the last two years. During the first 5 years, 1973 through 1977, accumulative sludge-borne Cd, Cu, Ni, and Zn applied on maximum-treated plots amounted to 87, 426, 108, and 1,321 kg/ha, respectively. During the last three years of the study amounts of solids applied each year were higher than in previous years, which resulted in concomitantly higher loading rates of sludge-borne metals. But overt symptoms of phototoxicity were never observed in corn.

As can be seen in Table 16, organic-C and total N were significantly increased in the 0 to 15 cm depth of strip-mine spoil as a result of annual sludge applications. But both remained fairly constant during the last three years of the study, indicating that an equilibrium between annual additions and decompositional losses of organic matter had been established. The equilibrium in spoil was attained at an organic matter content of about 1% less than in Blount silt loam treated with similar annual applications of sludge.

TABLE 14. CONCENTRATIONS AND TOTAL ANNUAL AMOUNTS OF SEVERAL CONSTITUENTS CONTAINED AT RELATIVELY HIGH CONCENTRATIONS IN SLUDGES APPLIED ON PLOTS OF STRIP-MINE SPOIL MATERIAL PLANTED TO CORN.

Year	Solids %	Total N	NH_4-N	P	K	Na	Ca	Mg	Fe
				Annual means					
				mg/l (wet wt.)					
1978	4.39	2215	971	1410	250	122	1630	579	1960
1979	4.69	2128	942	1400	211	108	1650	597	2130
	mt/ha			Total amounts applied annually					
				kg/ha					
1978	64.3	3378	1481	2150	381	186	2480	883	2990
1979	79.6	3786	1680	2480	375	192	2930	1060	3790

TABLE 15. CONCENTRATIONS AND TOTAL ANNUAL AMOUNTS OF SEVERAL METALS IN SLUDGES APPLIED ON PLOTS OF STRIP-MINED SPOIL MATERIALS PLANTED TO CORN.

Year	Mn	Zn	Cd	Cu	Ni	Cr	Pb
				Annual means, mg/l			
1978	21.4	219	15.2	86.8	23.4	170	57.2
1979	21.7	209	14.9	77.3	21.1	170	57.9
				Total amounts applied annually			
				kg/ha			
1978	32.6	334	23.2	132	35.7	259	87.2
1979	38.6	372	26.5	138	37.5	302	103

TABLE 16. TOTAL N, ORGANIC-C, pH, AND TOTAL CONCENTRATIONS OF MACRO-ELEMENTS AND MINOR ELEMENTS IN 0 TO 15, 15 TO 30, 30 TO 46, AND 61 TO 76 CM DEPTHS OF STRIP-MINED SPOIL MATERIAL IN PLOTS LOCATED IN FULTON COUNTY, ILLINOIS. a/b/

Parameter	Depth cm	Year	Sludge application rates				
			0	1/4 Max	1/2 Max	Max	LSD
			%				
Organic-C	0-15	1978	0.33	0.59	0.94	1.22	0.33**
		1979	0.40	0.60	0.81	1.36	0.38**
	15-30	1978	0.19	0.18	0.22	0.29	n.s.
		1979	0.20	0.16	0.21	0.30	n.s.
	30-46	1978	0.15	0.16	0.15	0.18	n.s.
		1979	0.16	0.16	0.15	0.21	n.s.
	61-76	1978	0.15	0.14	0.16	0.18	n.s.
		1979	0.14	0.14	0.15	0.15	n.s.
N	0-15	1978	0.067	0.084	0.110	0.144	0.035**
		1979	0.058	0.088	0.105	0.153	0.026**
	15-30	1978	0.045	0.044	0.043	0.055	n.s.
		1979	0.048	0.045	0.045	0.055	n.s.
	30-46	1978	0.036	0.041	0.043	0.041	n.s.
		1979	0.043	0.043	0.033	0.043	n.s.
	61-76	1978	0.040	0.042	0.043	0.041	n.s.
		1979	0.038	0.035	0.040	0.035	n.s.

(continued)

TABLE 16. (continued)

Param-eter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
			----------	----------	%	----------	----------
P	0-15	1978	0.079	0.088	0.142	0.207	0.059**
		1979	0.087	0.117	0.146	0.247	0.67**
	15-30	1978	0.052	0.054	0.063	0.068	n.s.
		1979	0.054	0.059	0.071	0.080	0.011**
	30-46	1978	0.035	0.040	0.032	0.047	n.s.
		1979	0.038	0.037	0.041	0.039	n.s.
	61-76	1978	0.033	0.041	0.033	0.034	n.s.
		1979	0.045	0.048	0.049	0.046	n.s.
K	0-15	1978	2.00	2.04	1.90	1.97	n.s.
		1979	1.96	2.05	2.00	2.02	n.s.
	15-30	1978	1.85	1.96	1.94	1.90	n.s.
		1979	2.11	2.08	2.05	2.06	n.s.
	30-46	1978	1.90	1.98	1.95	1.86	n.s.
		1979	2.22	1.97	2.05	1.98	n.s.
	61-76	1978	1.98	2.05	2.03	1.90	n.s.
		1979	2.08	2.12	1.84	2.04	n.s.

(continued)

TABLE 16. (continued)

Parameter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
			----------	%	----------		
Na	0-15	1978	0.760	0.626	0.618	0.715	n.s.
		1979	0.678	0.686	0.700	0.703	n.s.
	15-30	1978	0.659	0.644	0.712	0.658	n.s.
		1979	0.701	0.645	0.710	0.774	n.s.
	30-46	1978	0.748	0.676	0.765	0.725	n.s.
		1979	0.732	0.683	0.755	0.778	n.s.
	61-76	1978	0.772	0.724	0.792	0.825	n.s.
		1979	0.766	0.677	0.657	0.744	n.s.
Ca	0-15	1978	0.902	0.958	0.972	1.08	n.s.
		1979	0.882	0.901	0.959	0.946	n.s.
	15-30	1978	0.782	1.02	1.00	0.932	n.s.
		1979	0.834	1.01	1.07	0.831	n.s.
	30-46	1978	1.03	1.01	0.841	1.00	n.s.
		1979	0.873	1.01	1.09	0.773	n.s.
	61-76	1978	1.31	1.19	1.09	1.05	n.s.
		1979	0.939	1.08	0.952	1.09	n.s.

(continued)

TABLE 16. (continued)

Param-eter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
			-------------------	%	-------------------		
Mg	0-15	1978	0.586	0.731	0.648	0.782	n.s.
		1979	0.777	0.761	0.773	0.758	n.s.
	15-30	1978	0.699	0.830	0.759	0.706	n.s.
		1979	0.752	0.808	0.834	0.792	n.s.
	30-46	1978	0.829	0.857	0.856	0.887	n.s.
		1979	0.835	0.854	0.918	0.729	0.117*
	61-76	1978	0.777	0.965	0.944	0.863	n.s.
		1979	0.836	0.865	0.737	0.781	n.s.
Fe	0-15	1978	3.36	3.70	3.55	3.62	n.s.
		1979	3.03	3.50	3.49	3.41	0.39**
	15-30	1978	3.24	3.61	3.53	3.21	n.s.
		1979	2.97	3.23	3.07	3.06	n.s.
	30-46	1978	3.16	3.63	3.19	3.04	n.s.
		1979	3.75	3.55	3.47	3.23	n.s.
	61-76	1978	3.14	3.31	3.17	3.14	n.s.
		1979	3.74	4.18	3.96	3.57	n.s.

(continued)

TABLE 16. (continued)

Param-eter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
			mg/kg				
Mn	0-15	1978	686	736	638	666	n.s.
		1979	592	680	648	575	n.s.
	15-30	1978	512	741	638	569	n.s.
		1979	510	631	600	580	n.s.
	30-46	1978	669	745	672	612	n.s.
		1979	617	741	732	572	n.s.
	61-76	1978	622	824	634	609	n.s.
		1979	528	625	580	578	n.s.
Zn	0-15	1978	74	135	210	286	69**
		1979	82	150	208	345	80**
	15-30	1978	57	73	74	77	7**
		1979	56	70	75	95	26**
	30-46	1978	60	65	66	66	n.s.
		1979	63	62	60	62	n.s.
	61-76	1978	64	70	74	69	n.s.
		1979	61	70	62	63	n.s.

(continued)

TABLE 16. (continued)

Param-eter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
			mg/kg				
Cd	0-15	1978	1.0	4.8	7.8	15.2	5.9**
		1979	2.0	6.0	9.7	18.3	5.0**
	15-30	1978	<0.25	<0.25	0.55	0.74	0.35**
		1979	0.41	0.80	1.13	2.39	1.30*
	30-46	1978	<0.25	<0.25	<0.25	<0.25	n.s.
		1979	<0.25	0.36	0.54	0.75	0.36**
	67-76	1978	<0.25	<0.25	<0.25	<0.25	n.s.
		1979	<0.25	<0.25	0.53	0.66	n.s.
Cu	0-15	1978	31	51	78	110	29**
		1979	30	60	73	118	30**
	15-30	1978	26	33	41	38	8*
		1979	27	33	31	39	n.s.
	30-46	1978	29	35	38	50	n.s.
		1979	23	20	23	23	n.s.
	61-76	1978	42	31	33	26	n.s.
		1979	23	20	22	24	n.s.

(continued)

TABLE 16. (continued)

Param-eter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
			mg/kg				
Ni	0-15	1978	39	47	51	57	10*
		1979	44	47	53	66	9**
	15-30	1978	36	38	39	40	n.s.
		1979	42	48	47	61	n.s.
	30-46	1978	36	38	36	37	n.s.
		1979	46	40	40	45	n.s.
	61-76	1978	33	36	35	34	n.s.
		1979	45	49	45	52	n.s.
Cr	0-15	1978	77	126	174	232	61**
		1979	72	103	127	162	43**
	15-30	1978	71	76	83	88	n.s.
		1979	57	59	70	77	15**
	30-46	1978	73	74	72	77	n.s.
		1979	62	57	62	60	n.s.
	61-76	1978	76	76	76	78	n.s.
		1979	56	70	56	61	n.s.

(continued)

TABLE 16. (continued)

Parameter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
			---mg/kg---				
Pb	0-15	1978	14	29	45	68	16**
		1979	27	33	47	76	33**
	15-30	1978	12	13	15	15	n.s.
		1979	12	15	17	32	n.s.
	30-46	1978	13	12	14	14	n.s.
		1979	14	14	14	18	n.s.
	61-76	1978	9	10	9	9	n.s.
		1979	12	13	19	14	n.s.
			---units---				
pH	0-15	1978	7.3	7.5	7.4	7.2	0.2*
		1979	7.8	7.8	7.6	7.5	0.2**
	15-30	1978	7.2	7.5	7.4	7.4	n.s.
		1979	8.0	7.9	7.8	7.7	0.2**
	30-64	1978	7.3	7.4	7.2	7.3	n.s.
		1979	7.9	7.9	7.8	7.7	0.2*
	61-76	1978	7.2	7.4	7.3	7.0	0.3**
		1979	7.7	7.7	7.7	7.6	n.s.

a/ Concentrations are on a dry weight basis.

b/ Digested sludge was applied annually on replicated plots at various rates and control plots were annually treated with relatively high rates of inorganic fertilizer.

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

Sludge applications increased Ni and Pb in the 0 to 15 cm, P, Cu, Cr, and Zn in the 0 to 30 cm, and Cd in 0 to 46 cm depths of spoil. Only about one-third of the total amounts of these elements applied on strip-mine spoil as constituents of sludge can be accounted for by amounts accumulated in the 76 cm depth of spoil. Amounts of these elements that can be accounted for in level calcareous spoil are less by about 50% than those accounted for in acid Blount silt loam. Concentrations of K, Na, Ca, Mg, Fe, and Mn in spoil were not affected by sludge applications. Maximum sludge applications tended to decrease the pH of spoil, although the differences were relatively small and were not decreased below a pH of 7.

Grain and stover yields for 1978 are presented in Table 17. Yields were not determined in 1979 due to a severe crusting problem and drought conditions that reduced plant populations to less than 9,000 plants/ha. Although mean yields over all years since the study was initiated shows some advantage for sludge applications, yields in 1978 were lower on sludge-amended spoil than on control plots treated with inorganic fertilizer. In all years, yields have been disappointingly low, regardless of treatment. It appeared that the main reason for low yields was due to a restricted rooting depth, resulting in a moisture stress at the critical pollination growth stage. Irrigating with liquid sludge only partially alleviated the moisture stress.

Data presented in Table 18 shows that concentrations of leaf- Ca during the last year and leaf- Mg during both years were reduced by sludge applications. Concentrations of Mn and Cu were increased in leaves and stover during both years by sludge applications. Concentrations of Ni were increased by sludge treatments in grain and stover during both years, but not in leaf. Zinc and Cd concentrations were increased in all plant tissues by sludge applications. Concentrations of Zn and Cd in corn plant tissues from calcareous spoil were as high as those found in tissues of the same hybrid grown on acid Blount. Furthermore, the accumulations of sludge-borne Cd and Zn in calcareous spoil by repeated applications of sludge caused increased levels of these metals in plant tissues, but such accumulations in acid Blount affected Cd and Zn concentrations in corn to only a minor extent (Hinesly et al., 1981).

Summary and Conclusion

Further work is needed to determine 1) why digested sewage sludge failed to ameliorate the chemical and physical properties of strip-mine spoil that adversely affects the growth of row crops, 2) why some trace elements appeared to be more available for plant uptake, 3) how chemical elements applied as constituents of sludges are lost from strip-mined spoil, and 4) why losses of selected chemical elements from calcareous spoil were higher than those in acid Blount.

TABLE 17. PLANT POPULATIONS AND GRAIN AND STOVER YIELDS OF CORN GROWN ON STRIP-MINED SPOIL MATERIAL WITH AND WITHOUT DIGESTED SEWAGE SLUDGE IN 1978.

Sludge application rates				
0	1/4 Max	1/2 Max	Max	LSD
Plant Population				
number/ha				
47900	54100	46100	47300	
Grain yields				
mt/ha				
4.00	2.82	3.14	3.08	0.83*
Stover yields				
mt/ha				
5.52	5.74	6.66	7.07	n.s.

TABLE 18. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS IN CORN PLANT TISSUES FROM PLOTS OF STRIP-MINED SPOIL MATERIAL WITH AND WITHOUT SLUDGE.a/

Constituent	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
		%				
		Leaf				
N	1978	3.38	3.28	3.21	3.49	n.s.
	1979	2.77	2.81	2.78	3.20	n.s.
		Grain				
	1978	1.66	1.58	1.74	1.90	n.s.
	1979	1.91	1.66	1.86	1.72	n.s.
		Stover				
	1978	1.07	1.11	1.27	1.55	0.31*
	1979	1.66	1.20	1.43	1.66	n.s.
		mg/kg				
		Leaf				
P	1978	3130	3140	3060	3020	n.s.
	1979	3030	2330	2440	2900	517**
		Grain				
	1978	3200	3280	3370	3570	n.s.
	1979	2770	2440	2640	2450	n.s.
		Stover				
	1978	940	1070	1150	1590	n.s.
	1979	1730	1480	1450	1600	n.s.

(continued)

TABLE 18. (continued)

Constituent	Year	Sludge application rate 0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
				Leaf		
Ca	1978	7700	6950	7770	8320	821*
	1979	8530	7940	7240	5820	1950**
				Grain		
	1978	67	70	65	81	n.s.
	1979	61	44	56	59	n.s.
				Stover		
	1978	3300	3480	3430	3840	n.s.
	1979	4940	5200	5140	5520	n.s.
				Leaf		
Mg	1978	3370	3210	2940	2760	419**
	1979	4090	3270	3170	2540	879*
				Grain		
	1978	1300	1410	1390	1370	n.s.
	1979	1300	1220	1320	1160	n.s.
				Stover		
	1978	2440	2810	2880	2710	n.s.
	1979	3340	3260	3080	2920	n.s.

(continued)

TABLE 18. (continued)

Constituent	Year	0	1/4 Max	1/2 Max	Max	LSD
		Sludge application rates (mg/kg)				
				Leaf		
Fe	1978	119	123	124	129	n.s.
	1979	204	176	204	157	n.s.
				Grain		
	1978	21	19	21	22	n.s.
	1979	25	20	23	24	n.s.
				Stover		
	1978	375	184	234	158	n.s.
	1979	390	406	422	362	n.s.
				Leaf		
Mn	1978	81	64	96	155	32**
	1979	77	61	87	160	41**
				Grain		
	1978	6	6	6	6	n.s.
	1979	8	6	7	8	n.s.
				Stover		
	1978	57	55	62	90	21**
	1979	61	73	81	104	23*

(continued)

TABLE 18. (continued)

Constituent	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
				Leaf		
Zn	1978	48	114	201	317	72**
	1979	65	100	197	346	67**
				Grain		
	1978	27	37	44	51	7**
	1979	20	24	30	33	6**
				Stover		
	1978	32	97	183	345	47**
	1979	41	106	230	338	103**
				Leaf		
Cd	1978	1.91	7.20	16.9	33.7	7.63**
	1979	3.66	10.3	20.6	37.0	5.75**
				Grain		
	1978	0.160	0.280	0.410	0.830	0.12**
	1979	0.146	0.293	0.603	1.12	0.53**
				Stover		
	1978	2.14	7.70	16.2	40.0	9.54**
	1979	4.78	14.0	31.8	68.8	16.1**

(continued)

TABLE 18. (continued)

Constituent	Year	0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
				Leaf		
Cu	1978	8	8	10	11	1**
	1979	10	9	12	18	5**
				Grain		
	1978	1.7	1.7	1.8	1.6	n.s.
	1979	2.3	2.0	2.3	2.0	n.s.
				Stover		
	1978	4	5	6	6	1**
	1979	6	7	10	13	2**
				Leaf		
Ni	1978	<0.6	<0.6	<0.6	0.7	n.s.
	1979	<0.6	<0.6	<0.6	0.9	n.s.
				Grain		
	1978	<0.6	0.8	1.0	2.0	0.8**
	1979	<0.6	<0.6	<0.6	2.0	0.6**
				Stover		
	1978	<0.6	<0.6	0.9	1.6	0.5**
	1979	<0.6	0.8	1.1	1.9	0.8*

(continued)

TABLE 18. (continued)

Constituent	Year	Sludge application rates: 0	1/4 Max	1/2 Max	Max	LSD
		mg/kg				
				Leaf		
Cr	1978	0.8	0.3	0.5	0.7	n.s.
	1979	<0.1	<0.1	<0.1	<0.1	n.s.
				Grain		
	1978	0.3	<0.1	0.2	0.3	n.s.
	1979	<0.1	<0.1	<0.1	0.1	n.s.
				Stover		
	1978	1.1	1.8	2.2	1.1	0.8**
	1979	1.2	2.1	2.5	2.5	1.0*
				Leaf		
Pb	1978	0.8	1.2	0.7	<0.6	n.s.
	1979	0.7	0.7	1.6	0.7	n.s.
				Grain		
	1978	<0.6	<0.6	<0.6	<0.6	n.s.
	1979	<0.6	1.0	0.7	<0.6	n.s.
				Stover		
	1978	2.1	5.6	6.5	2.8	n.s.
	1979	1.4	1.4	2.0	1.9	n.s.

a/ Dry weight basis.

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

SECTION 5

SPECIAL STUDIES

CHANGES IN STRIP-MINE SPOIL CHARACTERISTICS AND RESPONSE OF PLANTS TO HIGH-RATE SEWAGE SLUDGE APPLICATIONS

Introduction

Methods of applying sludges on strip-mined lands that are consistent with crop production and erosion control are limited. Irrigation of growing crops is limited to systems that apply sludge below the crop canopy. Spray irrigation systems cannot be used because leaf surfaces are coated with sludge solids that reduce light absorption and, thus, photosynthetic production rates. Where stoniness is a problem, subsurface interjection cannot be used without incurring costly repairs. Perhaps the worst system yet devised for applying sludges are those involving the use of disc plows for incorporation. Disc plows cause subsurface compaction that exacerbates the low infiltration capacity of the predominantly weathered shale and/or glacial till material. This leads to increased runoff of water, with concomitant increases in rates of erosion.

The main objective in reshaping the surface of strip-mined lands should be to drain off excess water at a non-erosive rate. Sludge should be applied at rates and by methods that maximize the potential benefits of its organic matter contents to ameliorate physical properties of spoil that adversely affect the growth of plants. The technology needed to do this is available. Level-ridge terraces, equipped with surface inlets, can be used to control erosion. Sludge, dewatered to about 70% moisture, can be applied with ordinary farm manure spreaders.

On agricultural lands, maximum sludge loading rates should be regulated according to the potential for contaminating subsurface water supplies with nitrate-nitrogen. But on strip-mined lands that have subsided to form a compact structureless mass, water movement is too slow through such material to present a pollution hazard to ground water supplies. Protection of surface waters is the main concern and can be accomplished by controlling runoff waters with structures and monitoring quality of water in impoundments prior to its release. Maximum loading rates of dewatered sludge on strip-mined lands should be limited by the tolerance of plants to sludge constituents and their effects on crop quality.

To identify plants that would rapidly establish vegetative cover and cropping systems that minimize erosion losses from sludge-amended spoil and to compare effects of a large single application with an equal amount of sludge applied in increments, a one-time, relatively high, sludge-loading rate study was established on strip-mined spoil banks in Fulton County, Illinois.

Methods and Materials

An experimental site, with good surface drainage, was selected on spoil banks which had been in place for about 30 years. The spoil material had a silty clay loam texture, $CaCO_3$ equivalent of 3.2%, and pH value of 7.5. Replicated (three) plots, having the dimensions of 21 x 18 m, were treated with 0 (control), 224, 448, and 896 mt/ha (dry weight equivalent) of digested sewage sludge that had an average moisture content of 45%. Control plots received 123 kg/ha of N, P_2O_5, and K_2O each year prior to seeding wheat and rye. Following the application of sludge and its incorporation with a rotary plow, each main plot was subdivided into nine plots of 3 x 6 m and two additional plots of 6 x 18.2 m. Each of the smaller subplots were seeded with one of the following grasses: big bluestem (*Andropogon gerandi*), orchard grass (*Dactylis glomerata*), perennial ryegrass (*Lolium perenne*), redtop (*Agrostis alba*), reed canarygrass (*Phalaris arundinacea*), smooth brome (*Bromus inermis*), tall fescue (*Festuca elatior*), timothy (*Phleum pratense*), and western wheatgrass (*Agropyron smithii*). Rye (*Secal cereale*) or wheat (*Triticum vulgare*) was seeded on the two larger subplots. During the first week of May, 3 m wide strips of rye and wheat were killed with paraquat and corn (*Zea mays*) was planted in the dead residues with a no-till planter.

From strips (3 x 18.2 m) of wheat and rye that were not sprayed with paraquat the top four leaves from 150 randomly selected plants were collected just before head emergence. Grain and straw samples were collected at the time of harvest. The leaf adjacent to the primary ear shoots was collected from ten corn plants in each of the dead wheat and rye plots when about 10% of the plants had tasseled. The leaves were washed with distilled water, dried at 60°C and ground in a Wiley mill. Corn grain and stalk samples were collected at the time of harvest.

Samples of spoil were collected from all main plots before sludge applications were made and each spring from subplots after sludge was applied. Six 2.5 cm diameter samples were collected from each subplot with stainless steel tubes to a depth of 91 cm and composited by 15 cm depth increments, except the lower increment was 30 cm. Additional samples of the surface 15 cm depth were collected periodically for determination of organic carbon, nitrogen, conductivity of saturated extracts, and changes in physical properties.

Sludge and sludge-amended spoil samples were analyzed for C, N, P, K, Mg, Ca, Na, Fe, Mn, Zn, Cu, Cr, Pb, Ni, and Cd concentrations. Plant tissues were analyzed for contents of the same elements except C, K, Na. Chemical analyses were the same as those described for studies discussed previously in this report and the procedures for measuring physical properties were those described in Agronomy Monograph No. 9 (Black et al., 1965).

Results and Discussion

Chemical and Physical Properties of Spoil--

Concentrations of the several chemical elements of interest in sludge are shown in Table 19, along with concentrations in the 0-15 cm depth of sludge-amended spoil where various amounts of sludge were incorporated. Except for Mn, concentrations of all chemical elements were significantly affected by sludge applications. Potassium and Na concentrations in spoil were decreased by sludge applications while concentrations of all other selected elements were increased. Although the highest sludge application markedly increased organic-C and N concentrations in spoil, C to N ratios were changed only slightly from 10.9 to 10.3. The C to N ratio of sludge itself is intermediate between control plots and maximum-sludge-amended spoil. Two years after sludge was applied no significant changes in organic-C and total N concentrations in spoil were observed, indicating that the sludge organic matter was highly stabilized against further degradation, even before it was applied. Phosphorus and Fe contents were somewhat higher in the sludge used in this study, which was dredged from a storage reservoir, as compared to sludge drawn directly from anaerobic digesters at the same Chicago wastewater treatment plant. However, concentrations in sludge samples were not high enough to account for the concentrations of these two elements found in spoil amended with 896 mt/ha of sludge. During storage P and Fe may have been concentrated by precipitation and sedimentation processes, but samples of dewatered sludge collected from manure spreaders evidently did not contain concentrations as high as those actually applied.

Concentrations of selected chemical elements, present in strip-mine spoil to a depth of 90 cm, before sludge was applied are shown in Table 20. In comparison to these data, it can be seen in Table 21 that concentrations of C, Cr, Ni, and Zn were increased in the 15 to 30 cm depth after sludge was applied. Two years after sludge was applied, Cu concentrations in 15 to 30 cm and 30 to 45 cm depths had been increased by sludge application. Concentrations of Cd and Pb were increased at all depths above 60 cm with increasing sludge loading rates. Concentrations of Mg were increased at all sampling depths above 90 cm. At a depth of 15 to 30 cm, concentrations of chemical elements reflect those added as constituents of sludge which was incorporated in the upper portion of this zone, as a result of mixing with the rotary plow.. But, apparently Cd, Cu, and Pb had migrated to deeper zones by some process. Migration may have been by leaching or translocation by invertebrates and/or plant roots.

After sludge was incorporated with spoil, the surface pH (0 to 18 cm depth) was reduced from 7.5 to 7.0, 6.3, and 6.0 by 224, 448, and 896 mt/ha of sludge solids, respectively. These pH values remained fairly constant after incorporation. The pH of water saturated extracts, from spoil with and without sludge, are shown in Figure 1. These extract were obtained to determine differences in electrical conductivities associated with various sludge loading rates and these results are shown in Figure 2. Electrical conductivities ranged from 2.2 mmho/cm in spoil samples from control plots to 6.6 mmho/cm in spoil amended with 896 mt/ha of sludge.

The results obtained by standard methods of determining aggregate stabilities by wet sieving with the Yoder apparatus for 10 minutes are shown in Figure 3. Water stable aggregates greater than 0.25 mm increased from 12.2% in samples from control plots as compared to 42.1% in maximum sludge-amended spoil.

Table 19. Concentrations of selected chemical elements in sludge and the 0-15 cm depth of sludge-amended spoil bank material. Beginning in October of 1979, separate spoil samples were taken from plots planted to grasses (Gr) and corn (Co).

			Spoil (0-15 cm)				
			Sludge Application Rates				
			mt/ha				
Element	Sludge	Sampling date	0	224	448	896	LSD
			% (dry weight)				
Org.-C	12.20	7-78	1.38	2.45	4.17	5.89	1.10**
		10-78	1.40	2.84	4.89	7.51	1.09**
		4-79	1.11	2.63	4.33	5.69	1.23**
		10-79 (Gr)	1.50	2.83	5.34	8.20	1.17**
		10-79 (Co)	1.49	3.28	4.72	6.94	1.94**
		3-80 (Gr)	1.16	2.41	3.56	5.64	2.04**
		3-80 (Co)	1.12	1.98	3.04	5.87	1.01**
		7-80 (Gr)	1.59	2.41	3.26	4.81	1.47**
		7-80 (Co)	1.58	2.32	2.83	4.81	1.48**
N	1.17	7-78	0.127	0.202	0.303	0.590	0.064**
		10-78	0.125	0.224	0.446	0.609	0.096**
		4-79	0.102	0.236	0.401	0.554	0.088**
		10-79 (Gr)	0.125	0.258	0.416	0.612	0.161**
		10-79 (Co)	0.131	0.264	0.392	0.575	0.151**
		3-80 (Gr)	0.103	0.199	0.326	0.536	0.216**
		3-80 (Co)	0.093	0.147	0.289	0.550	0.093**
		7-80 (Gr)	0.120	0.175	0.305	0.482	0.118**
		7-80 (Co)	0.094	0.172	0.258	0.427	0.108**
P	3.60	7-78	0.044	0.529	1.08	2.85	0.546**
		10-78	0.083	0.797	1.99	2.82	0.700**
		4-79	0.080	0.779	1.90	3.51	0.876**
		10-79 (Gr)	0.080	0.982	1.86	3.66	0.790**
		10-79 (Co)	0.079	0.840	1.66	3.28	0.819**
		3-80 (Gr)	0.075	0.703	1.30	2.72	1.34**
		3-80 (Co)	0.067	0.470	1.12	2.77	0.602**
		7-80 (Gr)	0.087	0.501	1.24	2.19	0.523**
		7-80 (Co)	0.072	0.415	0.996	2.07	0.438**

n.s. = not significant.
* = significant at 0.05<P<0.01.
** = significant at P≤0.01.

Table 19. continued Concentrations of selected chemical elements in sludge and the 0-15 cm depth of sludge-amended spoil bank material. Beginning in October of 1979, separate spoil samples were taken from plots planted to grasses (Gr) and corn (Co).

			Spoil (0-15 cm)				
			Sludge Application Rates				
			mt/ha				
Element	Sludge	Sampling date	0	224	448	896	LSD
			% (dry weight)				
K	0.25	7-78	2.23	2.21	1.95	1.53	0.28**
		10-78	2.35	2.19	1.84	1.48	0.36**
		4-79	2.35	2.00	1.81	1.34	0.24**
		10-79 (Gr)	2.32	2.13	1.80	1.39	0.26**
		10-79 (Co)	2.39	2.20	1.94	1.44	0.17**
		3-80 (Gr)	1.80	1.61	1.73	1.47	n.s.
		3-80 (Co)	1.77	1.74	1.77	1.47	0.24**
		7-80 (Gr)	2.20	1.91	1.93	1.64	0.25**
		7-80 (Co)	2.31	2.01	1.96	1.60	0.34*
Na	0.04	7-78	0.997	1.12	0.884	0.874	n.s.
		10-78	0.853	0.741	0.703	0.557	0.124**
		4-79	0.970	0.874	0.725	0.550	0.137**
		10-79 (Gr)	0.895	0.805	0.650	0.537	0.144**
		10-79 (Co)	0.897	0.800	0.737	0.546	0.152**
		3-80 (Gr)	0.681	0.528	0.560	0.586	n.s.
		3-80 (Co)	0.639	0.590	0.607	0.544	n.s.
		7-80 (Gr)	0.900	0.563	0.750	0.629	0.185**
		7-80 (Co)	0.898	0.754	0.705	0.612	0.189*
Ca	4.04	7-78	0.683	1.07	1.55	2.25	0.685**
		10-78	0.604	0.880	1.70	2.29	0.422**
		4-79	0.612	1.09	1.69	2.32	0.523**
		10-79 (Gr)	0.582	0.967	1.43	2.50	0.575**
		10-79 (Co)	0.628	1.02	1.51	2.25	0.719**
		3-80 (Gr)	0.847	1.01	1.32	2.14	0.811**
		3-80 (Co)	0.759	0.863	1.40	2.02	0.932**
		7-80 (Gr)	0.600	0.549	1.16	1.60	0.350**
		7-80 (Co)	0.692	1.08	1.20	1.64	0.439*

n.s. = not significant.
* = significant at $0.05<P<0.01$.
** = significant at $P\leq 0.01$.

Table 19 . continued

Concentrations of selected chemical elements in sludge and the 0-15 cm depth of sludge-amended spoil bank material. Beginning in October of 1979, separate spoil samples were taken from plots planted to grasses (Gr) and corn (Co).

			Spoil (0-15 cm)				
			Sludge Application Rates				
			mt/ha				
Element	Sludge	Sampling date	0	224	448	896	LSD
			% (dry weight)				
Mg	1.70	7-78	0.795	1.02	1.05	1.40	0.371**
		10-78	0.802	0.809	1.10	1.24	0.249*
		4-79	0.980	1.02	1.13	1.29	0.168**
		10-79 (Gr)	0.919	1.02	1.03	1.30	0.151**
		10-79 (Co)	0.954	1.02	1.14	1.28	0.233**
		3-80 (Gr)	0.995	1.02	1.01	1.28	0.201*
		3-80 (Co)	1.04	0.997	1.07	1.26	0.169**
		7-80 (Gr)	0.949	0.537	1.00	1.08	0.166**
		7-80 (Co)	0.991	0.862	0.926	0.988	n.s.
Fe	6.85	7-78	4.48	4.94	6.00	8.08	2.22**
		10-78	3.76	4.68	6.44	8.37	0.84**
		4-79	3.76	4.48	6.32	8.26	1.75**
		10-79 (Gr)	3.76	4.94	6.17	9.10	1.50**
		10-79 (Co)	3.93	4.94	5.82	8.48	2.07**
		3-80 (Gr)	3.61	4.46	5.66	7.84	2.09**
		3-80 (Co)	3.75	4.36	5.30	7.81	1.18**
		7-80 (Gr)	4.07	4.57	5.48	7.03	1.16**
		7-80 (Co)	3.87	4.49	5.12	6.56	0.74**
			mg/kg (dry weight)				
Mn	817	7-78	630	636	621	722	n.s.
		10-78	629	600	662	677	n.s.
		4-79	548	654	652	625	n.s.
		10-79 (Gr)	598	602	619	648	n.s.
		10-79 (Co)	581	585	615	618	n.s.
		3-80 (Gr)	403	301	353	356	37.8**
		3-80 (Co)	435	398	445	366	n.s.
		7-80 (Gr)	556	565	592	639	n.s.
		7-80 (Co)	539	615	598	601	n.s.

n.s. = not significant.
* = significant at 0.05<P<0.01.
** = significant at P≤0.01.

Table 19. continued Concentrations of selected chemical elements in sludge and the 0-15 cm depth of sludge-amended spoil bank material. Beginning in October of 1979, separate spoil samples were taken from plots planted to grasses (Gr) and corn (Co).

			Spoil (0-15 cm) Sludge Application Rates				
			----mt/ha----				
Element	Sludge	Sampling date	0	224	448	896	LSD
			----mg/kg (dry weight)----				
Zn	4230	7-78	99.3	503	884	1660	603**
		10-78	87.6	627	1470	2550	321**
		4-79	84.8	729	1530	2500	750**
		10-79 (Gr)	94.9	991	1460	2770	595**
		10-79 (Co)	90.2	750	1350	2510	594**
		3-80 (Gr)	94.1	611	1380	2270	954**
		3-80 (Co)	94.2	475	993	2300	429**
		7-80 (Gr)	133	392	1040	1690	431**
		7-80 (Co)	91.9	440	905	1570	382**
Cd	276	7-78	0.545	28.6	59.3	140	50.3**
		10-78	0.307	36.4	98.5	157	19.4**
		4-79	0.715	42.5	95.4	161	36.5**
		10-79 (Gr)	0.793	48.4	96.5	171	39.1**
		10-79 (Co)	0.469	45.9	84.8	163	34.7**
		3-80 (Gr)	0.943	31.2	70.4	136	63.5**
		3-80 (Co)	0.484	22.2	56.4	142	25.0**
		7-80 (Gr)	2.29	23.6	59.1	110	34.0**
		7-80 (Co)	0.435	22.5	56.0	99.0	25.3**
Cr	2760	7-78	41.9	206	430	1130	408**
		10-78	47.6	215	566	994	152**
		4-79	43.6	390	847	1420	356**
		10-79 (Gr)	63.6	396	848	1550	487**
		10-79 (Co)	50.0	385	713	1240	363**
		3-80 (Gr)	53.8	310	625	1230	551**
		3-80 (Co)	52.4	235	529	1280	261**
		7-80 (Gr)	54.5	168	449	785	259**
		7-80 (Co)	47.9	177	360	720	204**

n.s. = not significant.
* = significant at $0.05<P<0.01$.
** = significant at $P\leq 0.01$.

Table 19 continued Concentrations of selected chemical elements in sludge and the 0-15 cm depth of sludge-amended spoil bank material. Beginning in October of 1979, separate spoil samples were taken from plots planted to grasses (Gr) and corn (Co).

			Spoil (0-15 cm)				
			Sludge Application Rates				
			mt/ha				
Element	Sludge	Sampling date	0	224	448	896	LSD
			mg/kg (dry weight)				
Cu	1380	7-78	36.6	174	345	684	158**
		10-78	29.9	192	463	746	101**
		4-79	26.5	213	431	693	158**
		10-79 (Gr)	32.9	244	478	828	174**
		10-79 (Co)	34.1	250	424	766	152**
		3-80 (Gr)	32.6	190	348	661	273**
		3-80 (Co)	32.4	144	299	680	109**
		7-80 (Gr)	35.0	144	333	544	135**
		7-80 (Co)	30.1	139	290	521	115**
Ni	284	7-78	35.8	62.6	99.5	176	54.1**
		10-78	39.9	79.4	129	201	22.8**
		4-79	44.4	88.8	138	203	37.6**
		10-79 (Gr)	30.4	64.6	114	172	31.3**
		10-79 (Co)	34.5	72.0	100	173	30.3**
		3-80 (Gr)	40.4	70.7	112	194	64.6**
		3-80 (Co)	38.3	69.4	105	196	24.8**
		7-80 (Gr)	45.7	61.9	103	153	36.4**
		7-80 (Co)	43.8	65.7	93.2	141	19.7**
Pb	1090	7-78	13.0	122	247	548	178**
		10-78	13.5	145	357	676	232**
		4-79	15.0	134	284	476	145**
		10-79 (Gr)	18.1	172	374	641	127**
		10-79 (Co)	18.8	178	318	604	111**
		3-80 (Gr)	18.7	140	269	540	251**
		3-80 (Co)	16.0	100	226	538	104**
		7-80 (Gr)	23.5	105	245	389	121**
		7-80 (Co)	12.5	103	212	389	111**

n.s. = not significant.
* = significant at 0.05<P<0.01.
** = significant at P≤0.01.

Table 20. Concentrations of selected chemical elements and pH of strip-mine spoil materials in 0- to 15-, 15- to 30-, 30- to 46-, 46- to 61-, and 61- to 91-cm depths calculated prior to sludge application. These data are means of composite samples taken from three replicated blocks of four experimental plots each.

Analyte	Strip-Mine Spoil Depths (cm) 0-15	15-30	30-46	46-61	61-91
	%				
org.-C	0.95	0.51	0.51	0.62	0.82
N	0.089	0.073	0.059	0.060	0.071
K	2.23	2.23	2.27	2.29	2.25
Na	1.04	0.823	1.04	1.12	1.07
Ca	0.790	0.692	0.739	0.619	0.874
Mg	0.980	0.780	0.932	0.993	0.966
Fe	3.67	3.65	3.86	3.64	3.93
	mg/kg				
Mn	589	551	602	664	614
Cd	0.31	0.521	<0.25	<0.25	<0.25
Cr	44.0	46.0	44.0	40.2	46.3
Cu	29.6	28.4	36.7	43.2	62.8
Ni	32.7	33.9	32.7	27.6	35.1
Pb	9.50	8.21	10.2	11.2	9.70
Zn	98.5	96.8	99.5	98.5	104
P	583	488	494	498	572
	units				
pH	7.4	7.4	7.6	7.5	7.6

Table 21. Concentrations of selected chemical elements in sludge-amended spoil bank materials in 0- to 15-, 15- to 30-, 30- to 46-, 46- to 61-, and 61- to 91 cm depths. [a/], [b/]

Analyte	Depths cm	Plot Type	Sludge Application Rates ---mt/ha--- 0	224	448	896	LSD
			--- % (dry weight) ---				
Org.-C	0-15	Corn	1.58	2.32	2.83	4.81	1.48**
		Grass	1.59	2.41	3.26	4.81	1.47**
	15-30	Corn	0.685	0.839	0.784	1.02	n.s.
		Grass	0.436	0.484	0.664	1.28	0.582**
	30-46	Corn	1.03	1.11	1.22	0.936	n.s.
		Grass	0.456	0.393	0.420	0.568	n.s.
	46-61	Corn	0.568	0.524	0.636	0.559	n.s.
		Grass	0.482	0.462	0.534	0.634	n.s.
	61-91	Corn	0.468	0.446	0.566	0.582	n.s.
		Grass	0.558	0.624	0.432	0.591	n.s.
N	0-15	Corn	0.094	0.172	0.258	0.427	0.108**
		Grass	0.120	0.175	0.305	0.482	0.118**
	15-30	Corn	0.063	0.078	0.085	0.108	0.023**
		Grass	0.066	0.084	0.093	0.113	n.s.
	30-46	Corn	0.058	0.063	0.085	0.074	n.s.
		Grass	0.068	0.065	0.047	0.063	n.s.
	46-61	Corn	0.065	0.064	0.069	0.068	n.s.
		Grass	0.063	0.042	0.050	0.067	n.s.
	61-91	Corn	0.061	0.058	0.063	0.069	n.s.
		Grass	0.062	0.063	0.058	0.069	n.s.
P	0-15	Corn	0.072	0.415	0.996	2.07	0.438**
		Grass	0.087	0.501	1.24	2.19	0.523**
	15-30	Corn	0.029	0.052	0.070	0.072	n.s.
		Grass	0.080	0.136	0.211	0.454	0.170**
	30-46	Corn	0.029	0.058	0.066	0.063	0.027*
		Grass	0.029	0.048	0.053	0.057	n.s.
	46-61	Corn	0.030	0.061	0.049	0.043	0.019*
		Grass	0.029	0.053	0.035	0.048	0.014*
	61-91	Corn	0.030	0.046	0.039	0.048	n.s.
		Grass	0.033	0.045	0.037	0.045	n.s.

(continued)

Table 21. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rates 0	224	448	896	LSD
			mt/ha				
			% (dry weight)				
K	0-15	Corn	2.31	2.01	1.96	1.60	0.336*
		Grass	2.20	1.91	1.93	1.64	0.254**
	15-30	Corn	2.30	1.84	2.14	2.15	0.239**
		Grass	2.08	1.85	2.12	2.09	0.173*
	30-46	Corn	2.28	1.90	2.21	2.16	0.202**
		Grass	2.25	1.88	2.25	2.22	n.s.
	46-61	Corn	2.19	1.81	2.18	2.13	0.105**
		Grass	2.26	1.71	2.22	2.19	0.192**
	61-91	Corn	2.34	1.92	2.22	2.250	0.223*
		Grass	2.20	1.82	2.14	2.150	n.s.
Na	0-15	Corn	0.898	0.754	0.705	0.612	0.189*
		Grass	0.900	0.563	0.750	0.629	0.185**
	15-30	Corn	0.932	0.577	0.747	0.857	0.109**
		Grass	0.759	0.542	0.744	0.778	n.s.
	30-46	Corn	0.906	0.620	0.823	0.807	0.160**
		Grass	0.891	0.645	0.822	0.842	n.s.
	46-61	Corn	0.883	0.531	0.727	0.777	0.109**
		Grass	0.915	0.547	0.749	0.813	0.129**
	61-91	Corn	0.901	0.575	0.757	0.748	0.197**
		Grass	0.820	0.597	0.793	0.729	0.144*
Ca	0-15	Corn	0.692	1.08	1.20	1.64	0.439*
		Grass	0.600	0.549	1.16	1.60	0.350**
	15-30	Corn	0.660	0.666	0.699	0.674	n.s.
		Grass	0.684	0.502	0.721	0.770	n.s.
	30-46	Corn	0.833	0.652	0.756	0.656	n.s.
		Grass	0.737	0.505	0.724	0.660	0.122*
	46-61	Corn	0.790	0.452	0.692	0.673	n.s.
		Grass	0.727	0.534	0.775	0.687	n.s.
	61-91	Corn	0.862	0.502	0.757	0.781	n.s.
		Grass	0.689	0.576	0.685	0.620	n.s.

(continued)

Table 21. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rates 0	224	448	896	LSD
			---mt/ha---				
			---% (dry weight)---				
Mg	0-15	Corn	0.991	0.862	0.926	0.988	n.s.
		Grass	0.949	0.537	1.00	1.080	0.166**
	15-30	Corn	0.990	0.520	0.840	0.936	0.218**
		Grass	0.982	0.486	0.833	0.905	0.129**
	30-46	Corn	1.030	0.560	0.891	0.844	0.061**
		Grass	0.981	0.583	0.938	0.883	0.271**
	46-61	Corn	0.994	0.468	0.831	0.850	0.110**
		Grass	0.998	0.423	0.892	0.892	0.235**
	61-91	Corn	1.02	0.523	0.796	0.857	0.175**
		Grass	0.901	0.530	0.906	0.792	0.235**
Fe	0-15	Corn	3.870	4.49	5.12	6.56	0.739**
		Grass	4.070	4.57	5.48	7.03	1.160**
	15-30	Corn	3.990	3.82	4.05	4.01	n.s.
		Grass	4.050	3.97	4.34	4.31	n.s.
	30-46	Corn	3.720	3.87	3.96	3.98	n.s.
		Grass	3.810	3.44	4.24	3.79	n.s.
	46-61	Corn	3.880	3.97	4.37	3.66	n.s.
		Grass	3.850	3.66	4.08	4.00	n.s.
	61-91	Corn	4.330	4.01	4.28	4.26	n.s.
		Grass	3.810	3.63	3.85	3.79	n.s.
			---mg/kg (dry weight)---				
Mn	0-15	Corn	539	615	598	601	n.s.
		Grass	556	565	592	639	n.s.
	15-30	Corn	544	542	539	589	n.s.
		Grass	559	489	668	571	n.s.
	30-46	Corn	544	529	568	571	n.s.
		Grass	579	500	594	544	46*
	46-61	Corn	561	499	589	581	n.s.
		Grass	567	582	605	632	n.s.
	61-91	Corn	608	556	593	676	n.s.
		Grass	570	518	531	616	n.s.

(continued)

Table 21. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rates ---mt/ha--- 0	224	448	896	LSD
			---mg/kg (dry weight)---				
Zn	0-15	Corn	91.9	440	905	1570	382**
		Grass	133.0	392	1040	1690	431**
	15-30	Corn	88.5	135	162	219	77.2*
		Grass	96.0	195	210	410	148**
	30-46	Corn	90.5	102	180	127	n.s.
		Grass	92.5	141	118	128	n.s.
	46-61	Corn	92.7	100	109	78.6	n.s.
		Grass	89.2	86.5	93.0	87.8	n.s.
	61-91	Corn	103.0	85.9	97.9	77.3	n.s.
		Grass	85.8	83.2	81.2	78.6	n.s.
Cd	0-15	Corn	0.435	22.5	56.0	99.0	25.3**
		Grass	2.29	23.6	59.1	110.0	34.0**
	15-30	Corn	<0.25	2.98	4.67	11.7	4.44**
		Grass	0.545	4.38	6.81	21.5	8.45**
	30-46	Corn	<0.25	1.15	5.96	5.08	n.s.
		Grass	0.273	0.986	1.64	4.16	1.98**
	46-61	Corn	<0.25	0.741	1.63	1.51	n.s.
		Grass	0.274	0.543	0.670	1.94	0.924*
	61-91	Corn	0.371	<0.25	0.650	1.48	0.921*
		Grass	0.294	<0.25	<0.25	1.30	n.s.
Cr	0-15	Corn	47.9	177	360	720	204**
		Grass	54.5	168	449	785	259**
	15-30	Corn	38.0	55.0	75.9	95.5	37.8**
		Grass	41.9	55.0	90.4	153	40.9**
	30-46	Corn	49.1	52.9	87.2	69.6	n.s.
		Grass	49.2	50.2	57.1	69.4	12.6*
	46-61	Corn	45.3	50.8	58.4	53.3	n.s.
		Grass	44.5	45.8	56.6	54.5	n.s.
	61-91	Corn	49.3	44.6	56.3	54.8	7.6*
		Grass	46.7	45.0	54.2	51.0	n.s.

(continued)

Table 21. (continued)

Analyte	Depths cm	Plot Type	0	224	448	896	LSD
			Sludge Application Rate				
			mt/ha				
			mg/kg (dry weight)				
Cu	0-15	Corn	30.1	139	290	521	115**
		Grass	35.0	144	333	544	135**
	15-30	Corn	27.4	36.6	50.1	68.6	19.7**
		Grass	27.1	42.4	63.9	144.	25.1**
	30-46	Corn	28.7	32.8	59.3	43.7	n.s.
		Grass	25.8	30.1	34.9	42.0	8.2**
	46-61	Corn	25.8	32.0	36.8	35.1	n.s.
		Grass	25.2	27.7	30.4	32.9	n.s.
	61-91	Corn	27.9	26.5	38.9	33.0	n.s.
		Grass	27.8	26.7	31.2	31.4	n.s.
Ni	0-15	Corn	43.8	65.7	93.2	141	19.7**
		Grass	45.7	61.9	103	153	36.4**
	15-30	Corn	43.2	40.9	44.2	47.4	3.6*
		Grass	44.9	41.5	46.8	60.3	12.8**
	30-46	Corn	43.1	38.9	46.7	41.4	n.s.
		Grass	42.7	38.7	43.7	43.9	n.s.
	46-61	Corn	43.2	39.5	41.3	39.1	n.s.
		Grass	45.1	37.0	41.2	38.9	3.9**
	61-91	Corn	45.3	38.2	40.2	41.1	4.5*
		Grass	41.3	40.4	37.6	38.7	n.s.
Pb	0-15	Corn	12.5	103	212	389	111**
		Grass	23.5	105	245	389	121**
	15-30	Corn	12.3	20.4	27.7	49.4	21.7**
		Grass	14.4	26.8	42.5	93.2	27.6**
	30-46	Corn	11.0	13.6	36.8	25.0	n.s.
		Grass	11.7	12.1	20.6	24.5	9.7*
	46-61	Corn	12.6	11.6	18.4	17.0	n.s.
		Grass	11.8	11.2	12.9	18.1	4.7*
	61-91	Corn	12.1	12.0	13.0	14.3	n.s.
		Grass	7.86	13.3	10.7	12.0	n.s.

(continued)

Table 21. (continued)

Analyte	Depths cm	Plot Type	Sludge Application Rate mt/ha 0	224	448	896	LSD
			pH units				
pH	0-15	Corn	7.57	7.43	6.96	6.44	0.74**
		Grass	7.55	7.41	6.95	6.42	0.62**
	15-30	Corn	7.62	7.69	7.44	7.16	0.30**
		Grass	7.40	7.66	7.32	7.18	n.s.
	30-46	Corn	7.24	7.68	7.23	7.31	n.s.
		Grass	7.68	7.59	7.28	7.39	n.s.
	46-61	Corn	7.62	7.60	7.35	7.44	n.s.
		Grass	7.35	7.53	7.48	7.37	n.s.
	61-91	Corn	7.35	7.71	7.41	7.42	n.s.
		Grass	7.60	7.61	7.40	7.25	n.s.

a/ Sludge was applied to plots in summer of 1978.

b/ Samples were taken from corn and grass plots in 1980.

* = Significant at $P \leq 0.05$.
** = Significant at $P \leq 0.01$.
n.s. = Not significantly different.

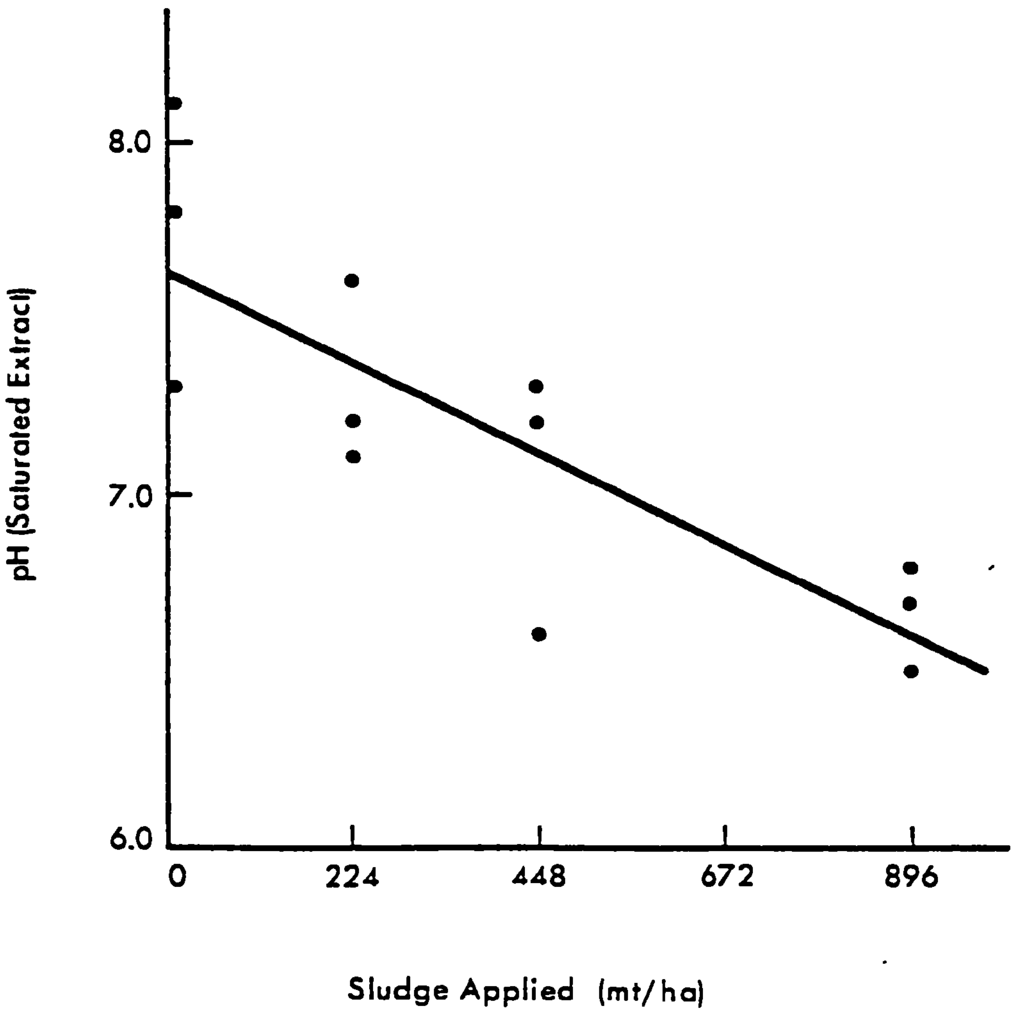

Figure 1. pH of Saturated Extracts from Strip-Mined Spoil Without and With Various Amounts of Incorporated Sewage Sludge.

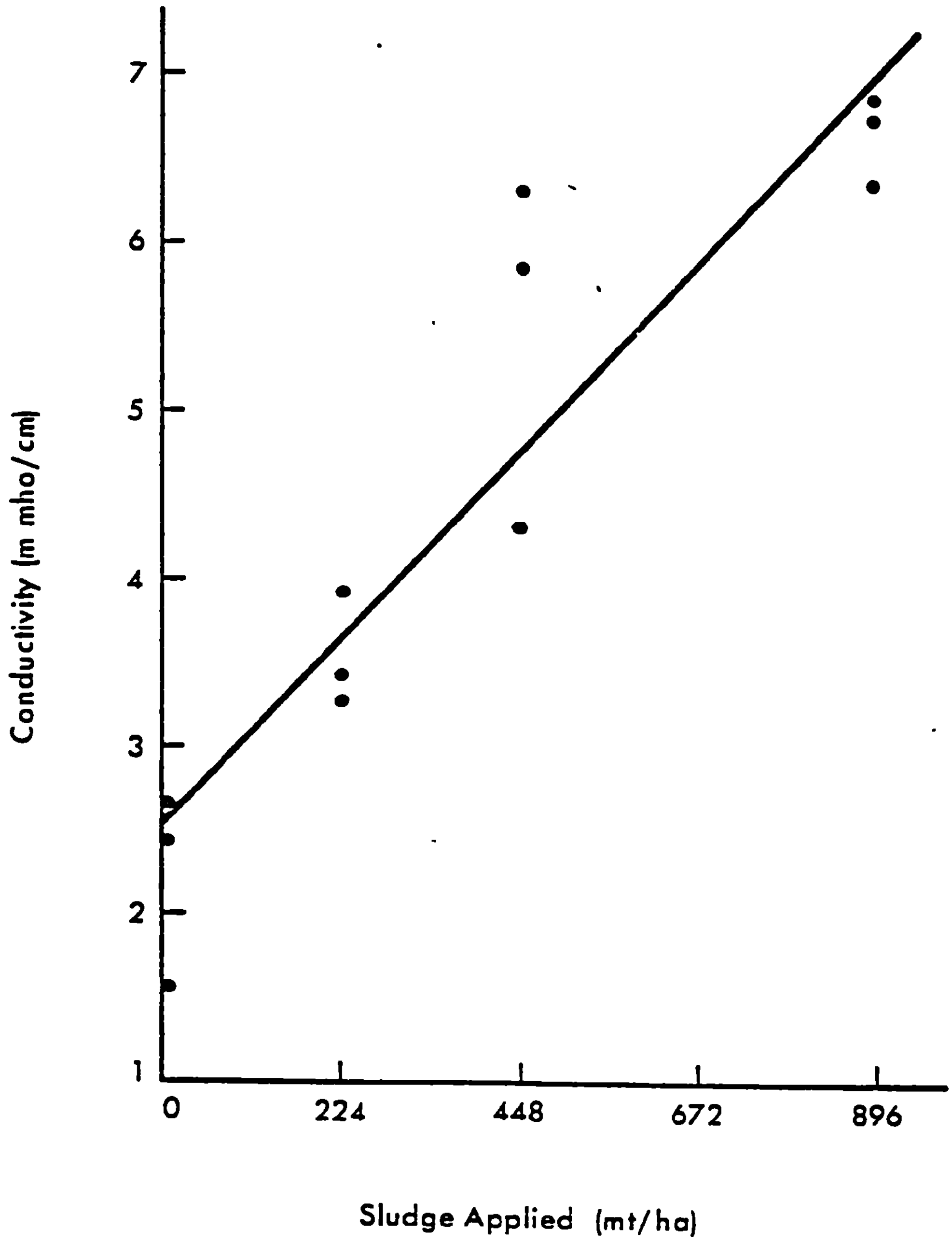

Figure 2. Electrical Conductivity of Saturated Extracts from Strip-Mined Spoil Without and With Various Amounts of Incorporated Sewage Sludge.

Figure 4 shows that the amounts of water retained at saturation and 1/3- and 15-bar matric tension increased in proportion to amounts of sludge applied. The rate of increase in moisture content at 1/3 bar was higher than that at 15 bar, thus, there was a small but significant increase in available moisture holding capacity with the two highest sludge application rates.

Crop Response--

Corn, wheat, and rye stover and grain yields are exhibited in Table 22. Corn grain yields on plots treated with low and intermediate sludge loading rates were significantly higher than those on fertilized control plots and plots treated with the highest rates of sludge, in the first year. Corn stover yields followed a similar pattern. In the second year, corn grain yields did not differ by treatment and were considerably less than those produced during the first year. But stover yields were higher in the second year. During the second year a severe moisture stress and unusual hot weather during the pollination period evidently reduced fertilization to such an extent that most ears were barren or partially barren of grain. Differences in corn yields between wheat and rye mulch were not significant, although the latter provided considerably better coverage of the spoil surface. Wheat was preferentially grazed by wild geese for such an extended period into the spring that grain development was severely reduced. Rye was not grazed as intensively as wheat, but yields may have been affected since there was no significant differences due to treatments. During the last year, rye produced significantly higher amounts of straw on plots treated with 448 mt/ha of sludge than on control and lesser sludge-treated plots.

Six weeks after the initial fall seeding of the nine species of grass, at a rate of 25 kg/ha, tall fescue and perennial ryegrass were the only ones present at acceptable stands on most plots. After seeding again in the spring, these two were followed by fairly good stands of western wheatgrass. All grasses were established except big bluestem following the second fall seeding. From the standpoint of rapid establishment and vigorous growth on all sludge-amended plots, tall fescue, perennial ryegrass and western wheat grass were the best by order of listing.

Inorganic Composition of Plant Tissues--

Regardless of whether corn was grown in rye or wheat mulch, higher sludge loading rates increased concentrations of P, Mn, Cd, and Zn in corn leaves during both years (Table 23). Corn leaf-Ni concentrations were increased by the highest sludge loading rate only during the first year. Lead concentrations in leaves of plants grown in dead wheat were significantly higher with higher sludge treatments during the first year, but not in the second year. It is noteworthy that leaf-Cd concentrations were only about 50% of those observed during the first year even though the same hybrid was planted. Also, in both years leaf-Cd concentrations were not increased by doubling the 448 mt/ha sludge application even though Cd concentrations in spoil were increased from 56 to 142 mg/kg (Table 19). Zinc contents of leaves also decreased during the second year, but, unlike Cd, concentrations of Zn in leaves were directly proportional to amounts of the metal supplied as a constituent of sludge.

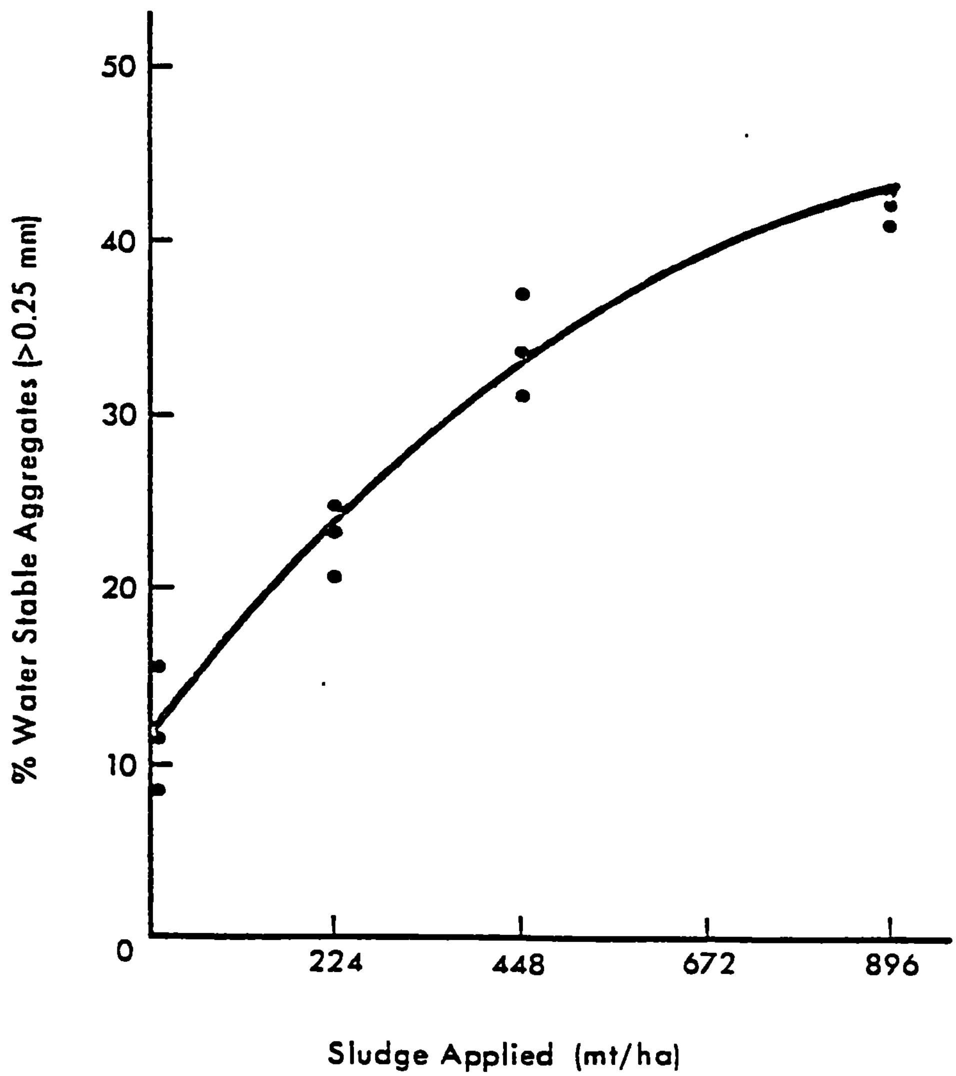

Figure 3. Percent Water Stable Aggregates in Strip-Mined Spoil Without and With Various Amounts of Incorporated Sewage Sludge.

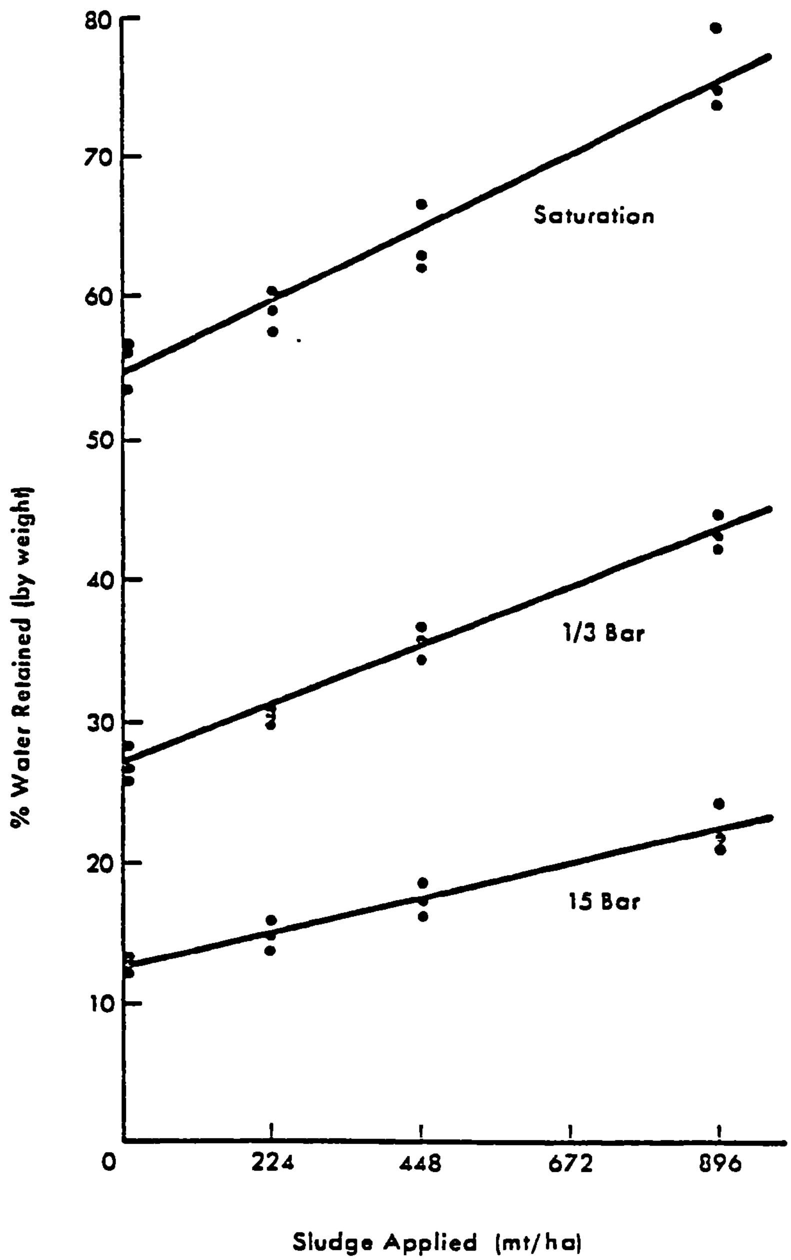

Figure 4. Percent Moisture Retention by Strip-Mined Spoil Without and With Various Amounts of Incorporated Sewage Sludge.

Table 22. Grain and stover yields for corn, wheat, and rye and plant populations for corn on spoil banks with and without sludge. Corn was planted in dead wheat (W) and rye (R) mulch with a no-till planter.

Year	Sludge Treatment	Corn (W)	Corn (R)	Wheat	Rye
		---Grain Yields (mt/ha)---			
1979	0	2.68	3.29	n.d.	2.61
	224	6.77	6.76	0.72[a]	2.36
	448	5.64	6.81	1.93[b]	2.41
	896	3.26	4.20	1.48[c]	2.33
	LSD	2.70**	2.15*	-	n.s.
1980	0	1.78	1.91	n.d.	0.304
	224	1.59	1.60	n.d.	0.496
	448	1.12	1.82	n.d.	0.918
	896	0.955	1.41	n.d.	1.04
	LSD	n.s.	n.s.	-	n.s.
		---Stover Yields (mt/ha)---			
1979	0	2.42	2.70	n.d.	n.d.
	224	6.60	5.75	n.d.	n.d.
	448	7.20	7.02	n.d.	n.d.
	896	3.67	3.82	n.d.	n.d.
	LSD	3.32**	2.13**	-	-
1980	0	4.13	3.84	n.d.	1.59
	224	7.30	7.42	n.d.	2.26
	448	8.15	9.57	n.d.	4.26
	896	7.52	7.41	n.d.	3.96
	LSD	n.s.	n.s.	-	1.74*
		---Plant Populations (1000/ha)---			
1979	0	31.3	36.7		
	224	58.2	50.0		
	448	58.2	60.2		
	896	36.3	42.4		
1980	0	28.9	28.1		
	224	38.3	38.3		
	448	43.2	47.8		
	896	41.0	41.6		

n.d. = no data due to bird damage.
a = only one plot.
b = only two plots.
c = three plots.
n.s. = not significant.
* = significant at $P \leq 0.05$.
** = significant at $P \leq 0.01$.

Table 23 Concentrations of selected elements in corn leaf from plots with and without sludge. Corn was planted with a no-till planter in dead wheat and rye.

		Planted in Dead Rye					Planted in Dead Wheat				
		Sludge Application Rates									
		mt/ha									
Element	Year	0	224	448	896	LSD	0	224	448	896	LSD
		% (dry weight)									
Mg	1979	0.48	0.44	0.46	0.58	0.07*	0.46	0.47	0.48	0.54	n.s.
	1980	0.47	0.43	0.51	0.72	0.15*	0.48	0.45	0.56	0.72	0.17*
Ca	1979	0.56	0.66	0.71	0.61	0.07*	0.61	0.64	0.74	0.71	n.s.
	1980	0.68	0.70	0.66	0.72	n.s.	0.60	0.70	0.78	0.70	n.s.
P	1979	0.24	0.28	0.32	0.35	0.07**	0.23	0.28	0.31	0.36	0.07**
	1980	0.24	0.29	0.29	0.30	0.03*	0.25	0.31	0.30	0.31	0.04*
N	1979	2.81	3.12	3.20	3.25	0.30*	2.85	2.96	3.13	3.21	n.s.
	1980	2.72	2.54	3.05	2.70	n.s.	2.74	2.59	2.97	2.79	n.s.
		mg/kg (dry weight)									
Zn	1979	51.7	105	201	276	108**	50.9	92.1	184	319	127**
	1980	48.5	67.2	106	159	66*	48.4	57.5	123	155	32**
Fe	1979	133	118	149	128	n.s.	148	131	144	138	n.s.
	1980	148	120	126	136	17**	145	125	126	132	n.s.
Mn	1979	25.4	43.4	72.0	178	45.4**	25.0	42.8	74.9	179	44.3**
	1980	44.0	37.5	45.8	97.2	34.3**	42.4	40.0	53.6	80.1	25.4**

*, ** = significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = no significant differences.

Table 23. Concentrations of selected elements in corn leaf from plots with and without sludge. Corn continued was planted with a no-till planter in dead wheat and rye.

		Planted in Dead Rye					Planted in Dead Wheat				
		Sludge Application Rates									
		mt/ha									
Element	Year	0	224	448	896	LSD	0	224	448	896	LSD
		mg/kg (dry weight)									
Ni	1979	<0.62	<0.62	<0.62	1.80	0.54**	<0.62	<0.62	<0.62	1.58	0.77**
	1980	<0.62	<0.62	<0.62	<0.62	n.s.	<0.62	<0.62	<0.62	0.99	n.s.
Cr	1979	<0.125	<0.125	<0.125	<0.125	n.s.	<0.125	0.185	0.246	0.285	n.s.
	1980	0.791	0.150	<0.125	0.149	n.s.	<0.125	0.209	0.125	<0.125	n.s.
Pb	1979	0.70	0.87	1.30	0.92	n.s.	0.74	0.92	0.94	1.09	0.18*
	1980	<0.62	<0.62	<0.62	<0.62	n.s.	<0.62	<0.62	<0.62	<0.62	n.s.
Cd	1979	0.334	3.10	11.0	14.5	6.76**	<0.062	2.29	12.2	16.4	8.59**
	1980	0.075	3.57	7.23	7.09	4.70**	<0.062	2.51	7.23	7.05	2.60**
Cu	1979	12.0	11.8	12.0	13.0	n.s.	11.1	11.4	11.9	13.9	n.s.
	1980	10.8	8.62	8.91	9.18	n.s.	11.2	9.11	8.75	9.15	n.s.

*, ** = significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = no significant differences.

In Table 24 it may be seen that concentrations of Cd, Ni, and Zn in grain were increased by sludge applications each year on all plots. Concentration of Mg and P were increased in the first but not the second year. Grain-Mn concentrations were increased by the highest sludge loading rate during both years on plots with rye and the first year with wheat residue mulches. Like leaf concentrations, grain-Cd was not increased by doubling the 448 mt/ha sludge application. Unlike leaf-Zn, concentrations of Zn in grain were similar to those of Cd in that the maximum sludge loading rate did not increase concentrations over those produced by the intermediate loading rate. This may have been due to the marked reduction in grain yields during the second year.

During both years, sludge applications increased Mg, P, Ni, Cd, Cu and Zn concentrations in rye grain (Table 25). Concentration of N and Fe in rye grain were increased the first year after sludge was applied. Although sludge applications increased Cd concentration in rye grain as compared to those in grain from control plots, during the second year Cd concentrations were unaffected by sludge loading rate. Rye stover had higher concentrations of Ca, Mg, N, P, Cd, Ni, and Zn during both years as a result of sludge applications. Concentrations of Cr, Fe, and Pb in rye stover were unaffected by sludge treatments and Mn concentrations were increased only during the first year.

Concentrations of P, Cd, Ni, and Zn in wheat grain, and P, Ca, Mg, Cd, Ni and Zn in wheat stover were increased by sludge applications (Table 26). As was the case with rye, Cd contents of wheat tissues were enhanced by sludge applications, but did not accumulate correspondingly higher concentrations of the metal with higher amounts of applied sludge-borne Cd. Leaves of wheat and rye (collected as heads were emerging from the boot) grown on sludge-amended spoil had higher concentrations of Mg, Mn, Cd, and Zn as compared to those collected from control plots (Table 27). Sludge applications also increased concentrations of P and Ni in the leaves of rye and N in leaves of wheat.

After rye and wheat were harvested, in the first year of the study, a forage sorghum (Sorghum vulgare) was seeded in the split-plots. Two months later, above ground whole plant samples of sorghum were harvested and analyzed for concentrations of the several elements listed in Table 28. For sorghum following rye, concentrations of P, Mg, Mn, Cd, Cu, Ni, and Zn were increased in whole plants. Concentrations of all of these elements except Mg and Mn had been significantly increased in spoil by sludge additions. Although concentrations of Ca, Fe, Cr, and Pb were increased in the surface layer (0-15 cm) of spoil their uptake by sorghum plants was not increased. Nickel and Zn were the elements whose concentrations were most consistently increased in tissues of all grass species by sludge applications. In agreement with data from corn, rye, wheat, and sorghum, concentrations of elements accumulated by grasses generally increased with higher sludge applications, except for Cd. Concentrations of Cd in the several kinds of plant tissues generally did not differ between the two highest sludge loading rates. All sludge loading rates resulted in about the same enhancement of Cd contents, when compared to Cd levels in plants from control plots.

Table 24. Concentrations of selected elements in corn grain from plots with and without sludge. Corn was planted with a no-till planter in dead wheat and rye.

		Planted in Dead Rye					Planted in Dead Wheat				
		Sludge Application Rates									
		mt/ha									
Element	Year	0	224	448	896	LSD	0	224	448	896	LSD
		% (dry weight)									
Mg	1979	0.12	0.14	0.14	0.14	0.01**	0.13	0.13	0.15	0.16	0.02*
	1980	0.12	0.16	0.16	0.16	n.s.	0.15	0.14	0.15	0.16	n.s.
Ca	1979	0.007	0.005	0.005	0.006	n.s.	0.006	0.007	0.005	0.004	n.s.
	1980	0.002	0.007	0.004	0.006	n.s.	0.004	0.005	0.006	0.004	n.s.
P	1979	0.28	0.31	0.36	0.36	0.03**	0.26	0.31	0.36	0.39	0.04**
	1980	0.30	0.37	0.36	0.39	n.s.	0.34	0.34	0.36	0.38	n.s.
N	1979	1.41	1.64	1.66	1.73	n.s.	1.52	1.72	1.72	1.84	n.s.
	1980	1.77	1.79	1.87	2.02	n.s.	1.65	1.85	2.29	2.22	n.s.
		mg/kg (dry weight)									
Zn	1979	27.5	33.3	36.9	42.2	7.86*	27.9	36.8	43.9	48.8	7.32**
	1980	25.0	37.6	43.5	52.7	19.4**	29.3	34.0	46.1	49.1	14.5*
Fe	1979	19.9	21.9	22.6	22.2	n.s.	24.9	32.5	31.7	34.9	4.98*
	1980	20.4	31.2	33.2	27.9	n.s.	27.6	25.2	25.7	27.8	n.s.
Mn	1979	8.54	7.37	7.46	8.91	1.18*	7.91	7.06	7.73	10.2	1.57**
	1980	7.69	6.96	7.40	10.5	2.38*	8.34	6.96	7.54	10.2	n.s.

*, ** = sginificantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = no significant differences.

Table 24. Concentrations of selected elements in corn grain from plots with and without sludge. Corn continued was planted with a no-till planter in dead wheat and rye.

		Planted in Dead Rye					Planted in Dead Wheat				
		Sludge Application Rates									
		mt/ha									
Element	Year	0	224	448	896	LSD	0	224	448	896	LSD
		mg/kg (dry weight)									
Ni	1979	0.63	0.83	1.39	3.43	1.38**	<0.62	0.62	1.48	3.07	1.04**
	1980	<0.62	0.77	1.32	2.51	0.98**	0.66	0.79	1.40	2.53	0.80**
Cr	1979	0.423	1.06	0.372	0.471	n.s.	<0.125	<0.125	<0.125	<0.125	n.s.
	1980	<0.125	<0.125	<0.125	<0.125	n.s.	<0.125	<0.125	<0.125	<0.125	n.s.
Pb	1979	<0.62	<0.62	<0.62	<0.62	n.s.	<0.62	<0.62	<0.62	<0.62	n.s.
	1980	<0.62	0.696	<0.62	<0.62	n.s.	0.94	<0.62	<0.62	0.68	n.s.
Cd	1979	<0.062	0.229	0.359	0.382	0.232**	<0.062	0.254	0.352	0.344	0.219**
	1980	0.071	0.346	0.613	0.488	0.261*	<0.062	0.266	0.524	0.399	0.308*
Cu	1979	2.80	2.67	2.50	2.75	n.s.	2.78	2.87	2.74	2.80	n.s.
	1980	1.80	2.50	2.16	2.03	n.s.	1.93	2.46	2.23	2.21	n.s.

*, ** = significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = no significant differences.

Table 25. Concentrations of selected elements in rye grain and stover from plots with and without sludge.

		Rye Grain					Rye Stover				
		Sludge Application Rates									
		mt/ha									
Element	Year	0	224	448	896	LSD	0	224	448	896	LSD
		% (dry weight)									
Mg	1979	0.119	0.125	0.148	0.169	0.020**	0.135	0.212	0.328	0.485	0.112**
	1980	0.142	0.153	0.170	0.164	0.017*	0.097	0.158	0.202	0.296	0.060**
P	1979	0.292	0.327	0.410	0.431	0.053**	0.040	0.053	0.143	0.229	0.108**
	1980	0.406	0.472	0.469	0.464	0.046*	0.070	0.162	0.170	0.226	0.069**
N	1979	2.08	2.28	2.64	2.62	0.42**	0.54	0.768	1.03	1.11	0.202**
	1980	1.96	2.30	2.37	2.44	n.s.	0.44	0.80	0.88	1.01	0.278**
		mg/kg (dry weight)									
Zn	1979	37.7	57.7	75.7	83.4	15.3**	13.2	40.5	94.1	122	60.5**
	1980	39.7	55.8	55.0	63.7	12.5*	21.5	43.6	71.1	106	35.5**
Fe	1979	41.5	42.0	47.6	47.9	5.36*	133	149	136	108	n.s.
	1980	63.6	53.1	85.7	42.9	n.s.	59.5	55.3	76.7	69.8	n.s.
Mn	1979	10.8	8.60	10.8	13.7	n.s.	14.6	10.2	16.0	35.8	11.9**
	1980	26.3	18.0	42.7	34.2	n.s.	13.5	11.4	42.0	25.6	n.s.
Ca	1979	439	458	448	412	n.s.	3130	4840	6290	5970	934**
	1980	437	456	504	403	n.s.	1880	2880	3020	3040	639*

Table 25. Concentrations of selected elements in rye grain and stover from plots with and without sludge. continued

		Rye Grain					Rye Stover				
		Sludge Application Rates									
		mt/ha									
Element	Year	0	224	448	896	LSD	0	224	448	896	LSD
		mg/kg (dry weight)									
Ni	1979	<0.62	<0.62	2.23	6.96	4.10**	<0.62	<0.62	1.61	4.92	3.35**
	1980	<0.62	<0.62	1.56	2.53	1.11**	<0.62	<0.62	1.15	2.58	1.20**
Cr	1979	0.178	0.140	0.182	0.249	n.s.	0.611	0.764	0.874	0.544	n.s.
	1980	0.863	0.604	1.10	1.25	n.s.	1.74	2.13	2.30	2.25	n.s.
Pb	1979	<0.62	<0.62	<0.62	<0.62	n.s.	0.862	<0.62	<0.62	<0.62	n.s.
	1980	2.63	2.63	1.96	3.73	n.s.	10.2	10.2	10.3	10.5	n.s.
Cd	1979	0.065	0.252	0.532	0.426	0.121**	0.069	0.847	2.03	2.20	1.34**
	1980	<0.062	0.329	0.387	0.389	0.176**	0.124	1.20	2.11	2.32	0.92**
Cu	1979	6.45	7.18	8.40	9.20	1.26**	3.55	4.80	7.34	10.2	4.31**
	1980	5.89	7.23	7.96	7.99	1.29**	3.16	4.57	5.73	6.93	1.31**

* = significant at $P \leq 0.05$
** = significant at $P \leq 0.01$
n.s. = not significantly different

Table 26. Concentrations of selected elements in wheat grain and stover from plots with and without sludge.

		Wheat Grain					Wheat Stover				
		Sludge Application Rates (mt/ha)									
Element	Year	0	224	448	896	LSD	0	224	448	896	LSD
		% (dry weight)									
Mg	1979	0.195	0.220	0.184	0.230	n.s.	0.196	0.242	0.290	0.559	0.267**
	1980			nd			0.171	0.210	0.249	0.310	0.066**
P	1979	0.330	0.381	0.393	0.535	0.123*	0.040	0.059	0.056	0.122	0.054**
	1980			nd			0.178	0.357	0.318	0.429	0.165*
N	1979	2.37	2.45	2.63	2.82	n.s.	0.489	0.815	0.665	0.784	n.s.
	1980			nd			0.911	1.22	1.25	1.40	n.s.
		mg/kg (dry weight)									
Zn	1979	52.0	67.0	68.3	84.3	19.0*	28.8	55.6	60.7	108	45.2**
	1980			nd			42.1	89.6	92.2	126	40.2*
Fe	1979	38.0	59.6	53.7	53.7	n.s.	670	459	238	184	n.s.
	1980			nd			145	149	123	160	n.s.
Mn	1979	48.7	27.4	33.7	40.1	n.s.	34.1	23.1	18.9	30.4	n.s.
	1980			nd			47.7	24.5	29.9	44.4	14.4*
Ca	1979	660	452	480	461	n.s.	2390	3040	3270	4770	1490*
	1980			nd			1630	2560	2940	2500	n.s.

n.s. = no significant differences.
*, ** = significant difference at $P \leq 0.05$ and $P \leq 0.01$, respectively.
nd = no data

Table 26. continued Concentrations of selected elements in wheat grain and stover from plots with and without sludge.

		Wheat Grain					Wheat Stover				
		Sludge Application Rates (mt/ha)									
Element	Year	0	224	448	896	LSD	0	224	448	896	LSD
		mg/kg (dry weight)									
Ni	1979	0.717	2.15	2.96	8.25	3.22**	1.41	1.11	1.23	4.33	1.60**
	1980	nd					0.62	1.27	1.11	3.62	n.s.
Cr	1979	1.44	2.48	1.07	0.120	n.s.	2.42	2.62	2.34	1.85	n.s.
	1980	nd					1.49	2.01	1.78	2.22	0.35*
Pb	1979	<0.62	<0.62	<0.62	<0.62	n.s.	<0.62	0.737	0.715	0.826	n.s.
	1980	nd					0.92	1.07	0.48	0.72	n.s.
Cd	1979	0.248	1.08	1.08	1.50	0.878**	0.555	1.95	2.15	2.76	1.35*
	1980	nd					0.180	3.94	4.18	4.50	2.79**
Cu	1979	4.18	5.31	4.47	4.92	n.s.	3.29	5.28	5.55	7.24	n.s.
	1980	nd					5.06	7.57	6.01	7.52	n.s.

n.s. = no significant differences.
*, ** = significant difference at $P \leq 0.05$ and $P \leq 0.01$, respectively.
nd = no data

Concentrations of selected chemical elements in eight species of grasses grown in control and sludge-treated plots are shown in Table 29. Stands of big bluestem were never adequately established on spoil materials. Samples of other species were collected from the first cutting on June 20. Applications of sludge significantly increased concentrations of the following elements in various species: N in redtop and orchard grass; P in brome, orchard, western wheat, and timothy; Mn in perennial rye and tall fescue; Cd in redtop, orchard, and western wheat; Cu in orchard, western wheat, reed canary; Ni in brome, orchard, western wheat, reed canary; perennial rye, timothy, and tall fescue; and Zn in all species except redtop. A trend for all elements except Ca, Fe, Cr, and Pb to increase in grasses was exhibited, but analytical results were too variable for these to be statistically significant. Nickel and Zn were the elements whose concentrations were most consistently increased in tissues of all grass species by sludge applications. In agreement with data from corn, rye, wheat, and sorghum, concentrations of elements accumulated by grasses generally increased with higher sludge applications, except for Cd. Concentrations of Cd in the several kinds of plant tissues generally did not differ between the two highest sludge loading rates.

Summary and Conclusions

The incorporation of sludge into the surface 0 to 18 cm of spoil materials produced a mixture that was about 8, 16, and 32 percent sludge for the three respective loading rates of 224, 448, and 896 mt/ha. Thus, the effect on physical properties were two fold. Physical properties of sludge itself were reflected in proportion to loading rates, and, secondly, some improvement in physical properties may have occurred as a result of stimulated microbial activity. However, because very little organic carbon was lost during the ten months that elapsed between incorporation of sludge and measurement of aggregate stability and available moisture holding capacity, microbes probably played only a minor role.

Because moisture contents at 1/3 bar increased more rapidly than at 15 bar of tension, available water holding capacity increased from 14.8% in spoil without sludge to 21.1% in spoil amended with 896 mt/ha of sludge. This increase in available moisture may have offset some of the deleterious effects on the growth of crops that were expected as a result of higher soluble salt contents in sludge-amended spoil.

The electrical conductivity (25^{o}C) of 6.6 m mho/cm for saturated extracts of maximum sludge-amended spoil was in the range where a 25 to 50% reduction in corn yields was expected (EPA, Water Quality Criteria, 1972). Thus, at the highest sludge loading rate the increase in potential available water holding capacity was small in comparison to the increased osmotic pressure of soil solution. Corn yields on plots treated with 224 mt/ha of sludge were about 50% higher than those on plots treated with 896 mt/ha and it appears that this reduction was due to high concentrations of soluble salts. Both rye and wheat are more tolerant of high salt conditions than is corn and the results of this study show that if yields of small grains were affected by soluble salts, it was a rather nominal effect. However, it was probably a major factor affecting the establishment of some of the grasses.

Table 27. Concentrations of selected elements in leaves of rye and wheat from plots with and without sludge.

		Rye					Wheat				
		Sludge Application Rates									
		mt/ha									
Element	Year	0	224	448	896	LSD	0	224	448	896	LSD
		% (dry weight)									
Mg	1980	0.171	0.348	0.373	0.512	0.116**	0.276	0.384	0.456	0.565	0.174**
Ca	1980	0.589	0.780	0.768	0.764	n.s.	0.245	0.377	0.437	0.534	n.s.
P	1980	0.180	0.275	0.290	0.348	0.090**	0.370	0.507	0.522	0.554	n.s.
N	1980	2.73	3.29	3.22	3.51	n.s.	4.14	4.73	4.95	4.82	0.17**
		mg/kg (dry weight)									
Zn	1980	13.4	21.9	30.4	39.9	11.7**	19.7	27.0	28.2	35.7	10.1**
Fe	1980	333	221	374	284	n.s.	144	126	120	112	n.s.
Mn	1980	32.0	26.1	33.7	61.5	21.2**	60.7	36.2	51.4	87.8	29.7*
Ni	1980	<0.62	<0.62	0.786	1.05	0.50*	<0.62	<0.62	<0.62	<0.62	n.s.

n.s. = no significant differences.
*, ** = significant difference at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Table 27. continued Concentrations of selected elements in leaves of rye and wheat from plots with and without sludge.

		Rye					Wheat				
		Sludge Application Rates									
		mt/ha									
Element	Year	0	224	448	896	LSD	0	224	448	896	LSD
		mg/kg (dry weight)									
Cr	1980	1.24	1.11	1.73	2.30	n.s.	0.850	0.753	0.850	0.931	n.s.
Pb	1980	1.23	1.67	2.82	2.74	n.s.	<0.62	<0.62	0.86	<0.62	n.s.
Cd	1980	0.079	0.407	0.696	0.924	0.402**	0.312	0.668	1.04	1.34	n.s.
Cu	1980	7.51	10.1	16.5	13.6	5.21*	9.11	10.8	10.4	10.3	n.s.

n.s. = no significant differnences.
*, ** = significant difference at P≤0.05 and P≤0.01, respectively.

Table 28. Concentrations of selected elements in sorghum whole plant from plots with and without sludge. Sorghum was planted in dead wheat and rye in July of 1979.

	Planted in Dead Rye					Planted in Dead Wheat				
	Sludge Application Rates									
	mt/ha									
Element	0	224	448	896	LSD	0	224	448	896	LSD
	% (dry weight)									
Mg	0.312	0.335	0.469	0.511	0.152*	0.313	0.398	0.554	0.688	0.129**
Ca	0.322	0.304	0.285	0.340	n.s.	0.291	0.340	0.369	0.322	0.048**
P	0.217	0.184	0.179	0.180	0.027*	0.213	0.223	0.258	0.251	n.s.
N	1.53	2.02	2.00	1.82	n.s.	1.86	2.17	2.51	2.29	0.40**
	mg/kg (dry weight)									
Zn	45	55	69	77	20**	49	66	110	137	46*
Fe	143	110	125	109	n.s.	160	118	122	137	n.s.
Mn	30	23	35	51	17**	29	28	41	88	26**
Ni	0.933	0.571	0.994	1.81	0.647*	0.998	1.09	2.15	3.78	1.22**
Cr	0.614	0.402	0.615	0.440	n.s.	0.455	0.341	0.645	0.660	n.s.
Pb	<0.62	<0.62	<0.62	<0.62	—	<0.62	<0.62	<0.62	<0.62	—
Cd	0.368	3.87	3.10	4.83	3.14**	0.571	6.41	10.7	9.93	6.20*
Cu	7.47	9.31	10.6	10.3	1.74**	9.30	9.03	11.7	11.9	n.s.

n.s. = no significant differences.
*, ** = significant difference at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Table 29 . Concentrations of selected elements in various grasses grown in 1980 on plots with and without sludge.

Analyte	Sludge Application Rates ---mt/ha--- 0	224	448	896	LSD
			Redtop		
		% (dry weight)			
Mg	0.177	0.224	0.244	0.242	n.s.
Ca	0.227	0.246	0.276	0.209	n.s.
P	0.203	0.236	0.230	0.218	n.s.
N	0.973	1.76	1.52	1.93	0.591*
		mg/kg (dry weight)			
Zn	20.5	44.5	61.3	59.0	n.s.
Fe	52.1	64.4	63.7	51.8	n.s.
Mn	61.9	59.3	75.5	86.6	n.s.
Ni	0.996	2.74	5.17	7.90	n.s.
Cr	0.750	0.876	0.199	0.440	0.443*
Pb	<0.62	<0.62	<0.62	<0.62	——
Cd	<0.062	0.296	0.954	0.684	0.618*
Cu	4.55	6.61	7.33	7.33	n.s.
			Brome		
		% (dry weight)			
Mg	0.120	0.196	0.196	0.290	0.082*
Ca	0.185	0.270	0.234	0.270	0.065**
P	0.135	0.194	0.240	0.291	0.108**
N	1.19	1.26	1.65	1.62	n.s.
		mg/kg (dry weight)			
Zn	15.3	33.6	49.0	61.7	24.5**
Fe	140	71.7	63.4	99.8	n.s.
Mn	45.6	23.4	28.5	61.0	20.8*
Ni	<0.62	0.837	1.91	3.50	1.64**
Cr	0.893	0.692	0.884	1.62	n.s.
Pb	<0.62	<0.62	<0.62	<0.62	——
Cd	0.417	1.28	1.69	2.21	n.s.
Cu	6.14	6.76	7.57	10.3	n.s.

*,** - Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively
n.s. - No significant differences

Table 29 . continued Concentrations of selected elements in various grasses grown in 1980 on plots with and without sludge.

	Sludge Application Rates				
	mt/ha				
Analyte	0	224	448	896	LSD
	Orchard				
	% (dry weight)				
Mg	0.293	0.297	0.316	0.358	n.s.
Ca	0.307	0.264	0.270	0.228	n.s.
P	0.203	0.267	0.311	0.365	0.086*
N	1.07	2.29	2.35	2.56	0.98**
	mg/kg (dry weight)				
Zn	19.5	36.2	50.6	66.6	27.6**
Fe	94.5	75.0	86.3	78.8	n.s.
Mn	106	39.6	52.5	122	52.8**
Ni	1.50	2.17	5.07	12.2	6.03**
Cr	0.392	0.428	0.646	0.598	n.s.
Pb	<0.62	<0.62	<0.62	<0.62	——
Cd	0.064	1.08	1.86	1.87	1.00*
Cu	4.42	9.18	11.8	13.2	4.39*
	Western Wheat				
	% (dry weight)				
Mg	0.131	0.154	0.158	0.195	0.033*
Ca	0.166	0.209	0.185	0.167	n.s.
P	0.141	0.187	0.191	0.222	0.040*
N	1.32	1.55	1.53	1.60	n.s.
	mg/kg (dry weight)				
Zn	18.0	33.6	40.0	45.6	20.0**
Fe	57.9	75.6	65.2	85.1	n.s.
Mn	30.2	22.6	22.6	33.6	7.8*
Ni	<0.62	<0.62	1.41	2.45	1.47**
Cr	1.16	0.972	1.08	1.71	n.s.
Pb	<0.62	<0.62	<0.62	<0.62	——
Cd	<0.062	0.815	1.07	0.892	0.720**
Cu	3.89	4.92	5.41	6.24	1.12*

*,** - Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively
n.s. - No significant differences

Table 29. continued Concentrations of selected elements in various grasses grown in 1980 on plots with and without sludge.

	Sludge Application Rates				
	mt/ha				
Analyte	0	224	448	896	LSD
			Reed's Canary		
	% (dry weight)				
Mg	0.244	0.275	0.300	0.358	n.s.
Ca	0.261	0.258	0.258	0.228	n.s.
P	0.240	0.349	0.383	0.399	n.s.
N	1.64	2.29	2.24	2.23	n.s.
	mg/kg (dry weight)				
Zn	34.6	95.9	131	125	51.8*
Fe	66.5	72.5	91.2	79.8	n.s.
Mn	59.8	56.8	86.8	96.0	n.s.
Ni	1.74	4.17	8.98	11.5	5.08**
Cr	0.991	1.08	1.39	1.22	n.s.
Pb	<0.62	<0.62	<0.62	<0.62	——
Cd	<0.062	0.539	1.09	0.773	n.s.
Cu	6.18	9.35	11.3	12.4	4.50*
			Perennial Rye		
	% (dry weight)				
Mg	0.216	0.282	0.335	0.403	n.s.
Ca	0.252	0.316	0.436	0.454	n.s.
P	0.205	0.260	0.357	0.411	n.s.
N	1.02	1.68	2.27	1.73	n.s.
	mg/kg (dry weight)				
Zn	21.8	43.9	73.9	116	49.3*
Fe	87.2	70.0	90.4	190.5	n.s.
Mn	41.4	37.9	61.9	144	42.3**
Ni	1.09	3.10	9.24	22.8	9.79**
Cr	0.964	0.904	0.915	2.64	n.s.
Pb	0.66	<0.62	<0.62	4.84	n.s.
Cd	<0.062	0.129	0.887	2.51	n.s.
Cu	3.83	6.10	10.2	16.5	n.s.

*,** - Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively
n.s. - No significant differences

Table 29 . continued Concentrations of selected elements in various grasses grown in 1980 on plots with and without sludge.

	Sludge Application Rates				
	mt/ha				
Analyte	0	224	448	896	LSD
	Timothy				
	% (dry weight)				
Mg	0.120	0.163	0.175	0.227	0.061**
Ca	0.163	0.187	0.198	0.175	n.s.
P	0.214	0.247	0.267	0.272	0.032*
N	1.24	1.36	1.38	1.18	n.s.
	mg/kg (dry weight)				
Zn	26.3	46.4	75.6	82.2	39.1*
Fe	107	67.6	59.8	65.6	n.s.
Mn	31.7	30.9	39.3	51.8	n.s.
Ni	0.816	2.29	4.25	9.94	6.43**
Cr	1.10	1.05	1.17	1.40	n.s.
Pb	<0.62	<0.62	<0.62	<0.62	——
Cd	<0.062	<0.062	0.454	0.485	n.s.
Cu	7.58	6.89	8.31	10.1	n.s.
	Tall Fescue				
	% (dry weight)				
Mg	0.214	0.291	0.321	0.339	n.s.
Ca	0.252	0.299	0.298	0.263	n.s.
P	0.191	0.233	0.267	0.278	n.s.
N	1.17	2.23	2.15	1.92	n.s.
	mg/kg (dry weight)				
Zn	20.8	28.0	42.4	46.8	16.1*
Fe	76.0	80.0	91.5	88.4	n.s.
Mn	31.7	25.9	36.8	61.8	18.4**
Ni	1.10	1.82	4.84	7.17	2.42**
Cr	1.03	0.414	1.00	0.784	n.s.
Pb	<0.62	<0.62	0.665	<0.62	n.s.
Cd	0.318	0.674	1.13	1.28	n.s.
Cu	4.40	5.53	6.69	6.70	n.s.

*,** - Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively
n.s. - No significant differences

Western wheatgrass has high salt tolerance and while perennial ryegrass and tall fescue have only medium tolerance, they are more tolerant than the other grass species used in this study. Soluble salts appear to be the major factor affecting crop growth and survival of grasses at the seedling stage on spoil amended with sludge at loading rates which exceed 224 mt/ha.

For elements that had increased concentrations in spoils as a result of sludge applications and which were accumulated by corn plants by uptake and translocation into leaves and grain, concentration ratios (CR) were calculated and are presented in Table 30. Indigenous concentration ratios were obtained by dividing the concentrations of a particular element in leaves or grain from control plots by total concentrations of that element in spoil materials that were not treated with sludge. Amended concentration ratios were calculated by subtracting concentrations in leaves or grain from control plots from those in similar tissues from sludge-amended plots and dividing by the remainder obtained by subtracting indigenous concentrations in spoil from concentrations in sludge-amended spoil. These concentration ratios are similar to those presented by Cataldo and Wildung (1978), except that they added a single concentration of each element (2.5 mg/kg) to the soil.

The CRs that could be calculated for corn leaves (Table 30) show that, except for Ni, the constituents of sludge were either not as available for uptake as indigenous elements or their uptake was limited by metabolically regulated processes.

In soil amended with soluble salts of metals, Cataldo and Wildung (1978) found CRs increased for As, Co, Cr, Mn, Mo, Ni, Pb, Sb, and Zn. In this study Mn was not increased in spoil by sludge applications because concentrations in sludge were no higher than those in untreated spoil materials. Previous analysis of sludge from the wastewater treatment plant showed that As, Co, and Mo concentrations were too low to increase total concentrations in normal soils (Hinesly and Sosewitz, 1969) and this has been borne out by determining concentrations in soils treated with annual sludge applications beginning in 1967 (Hinesly and Hansen, 1979). Concentration ratios could not be calculated for Cr and Pb because they were not increased in corn tissues, although levels of these two metals were markedly increased in sludge-amended spoil.

Concentrations of Ca in corn grain were not affected by sludge treatments as they were in leaves, so CRs for this element could not be calculated for grain (Table 30). Iron concentrations in leaves were not affected by sludge treatments, but were in grain from corn grown in wheat mulch. Since Zn concentrations were higher in grain from wheat mulch as compared to rye mulch plots, CRs from Zn in grain from the two different plots were calculated separately. As was the case for leaves, all CRs for grain produced on sludge-amended spoil were lower than those for grain from control plots, except for Ni. Concentration ratios for Ni tended to increase with increased sludge loading rates.

Table 30. Corn Leaf and Grain (1979) Concentration Ratios for Comparing the Uptake of Indigenous Elements to Those Added as Constituents of Sludge.

A.

	CORN LEAF CONCENTRATION RATIOS			
		Amended CR		
		Sludge Application Rates		
		---mt/ha---		
ELEMENT	Indigenous CR	224	448	896
N	27.70	1.57	1.14	0.88
P	2.93	0.07	0.04	0.03
Ca	0.96	0.13	0.12	0.02
Mg	0.48	-0.38	-0.01	0.29
Zn	0.60	0.07	0.10	0.10
Cd	0.27	0.06	0.12	0.10
Ni	0.007	0	0	0.009

B.

	CORN LEAF CONCENTRATION RATIOS			
		Amended CR		
		Sludge Application Rates		
		---mt/ha---		
ELEMENT	Indigenous CR	224	448	896
N	14.30	1.64	0.77	0.71
P	3.43	0.05	0.04	0.03
Mg	0.13	0.28	0.12	0.07
Fe (W)	6.62×10^{-4}	10.6×10^{-4}	2.66×10^{-4}	2.22×10^{-4}
Zn (R)	0.324	0.009	0.006	0.006
Zn (W)	0.329	0.014	0.011	0.009
Cd	0.043	0.005	0.003	0.002
Ni	0.007	0.009	0.012	0.018

(R) = Corn on rye.
(W) = Corn on wheat.

Because the pH was reduced from 7.5 to 6.0 on spoil amended with 896 mt/ha of sludge the decrease in concentration ratios with higher sludge loading rates is contrary to expectations. Also, since the highest corn yields were obtained with 224 mt/ha of sludge it is contrary to expectations that CR's decreased with higher loading rates that resulted in lower yields. Except perhaps for Ni, there is no evidence that metal concentrations in corn tissues were increased as a result of reduction in growth.

The corn hybrid used in this study was the same as that used in the previous study discussed in this report where sludge from the same treatment plant was applied each year at maximum annual loading rates that were about 50 mt/ha. In some years, this hybrid accumulated Cd concentrations in grain of around 1 mg/kg. Therefore, it is unlikely that the accumulation of Cd and other elements in corn tissues from this high-rate study was limited by metabolic controls. Rather, it appears that with these exceedingly high sludge loading rates, some of the elements were less available for uptake. At such high loading rates the availability of some metals may be controlled to a much greater extent by the properties of sludge itself than those of the weathered geological materials. In the presence of excessive levels of oxidizable sludge organic matter, sparingly soluble sulfide forms of some metals may be rather stable and thus, availability of metals for uptake by plants may be maintained at low levels until the organic matter has been decomposed. However, it seems unlikely that they will become more available in time because results from other studies discussed in this report showed that Zn and Cd uptake decreased after sludge-applications were terminated. In view of the findings reported by others (Cunningham et al., 1975), it seems more likely that the high amounts of Fe and P supplied as constituents of sludge limited the availability of some of the metals by forming sparingly soluble complexes.

Based on the results of feeding studies (Hinesly and Hansen, 1979, Hinesly et al., 1981), there is no indication that feeding the grains and forages produced on strip-mine spoil amended with high rates of sewage sludge would present a potential health hazard to animals. Feeding the materials to animals would present a nominal impact on food-chains, if any at all. Considering the relatively low enhancement of Cd and high enhancement of several essential trace elements, especially Zn and Cu, feed materials produced on sludge-amended spoil may actually be a higher quality feed than that produced with inorganic fertilization.

Further work is needed to determine the rate and extent of the migration of trace elements to deeper depths in calcareous spoil amended with high loading rates of sludge. Also, further work is needed to determine changes in trace element availability to plants with time under these conditions.

DIFFERENTIAL ACCUMULATIONS OF CADMIUM AND ZINC BY CORN (*Zea Mays* L.) HYBRIDS GROWN ON SOIL AMENDED WITH SEWAGE SLUDGE

Introduction

In a prior study twenty corn inbreds, commonly used as parents of hybrids adapted to the cornbelt region, were screened according to their capacities to accumulate Zn and Cd in leaves and grain when grown on Blount silt loam (Aeric ochraqualf, fine, illitic, mesic) with and without amendments with a metalliferous sewage sludge (Hinesly et al., 1978). Where maximum amounts of sludge had been applied annually for seven years, the soil surface (0-15 cm) contained 454 and 21 mg/kg of Zn and Cd, respectively, compared to 68 and 0.3 mg/kg in control plots treated with commercial fertilizers. Concentrations of Zn in leaves from different inbreds grown on maximum-sludge-treated plots ranged from 62 to 282 mg/kg and concentrations in grain from three inbreds (H99, Oh545, and R805) were not significantly increased by sludge-borne applications of Zn and Cd. Such extreme differences in capacities to accumulate Zn and Cd as were found in this small sample of inbreds raised the question of whether or not the differences in Zn and Cd accumulations were genetically predisposed, and, if so, how they were inherited.

Before experiments could be designed to determine the nature of the genetic component controlling the accumulation of transition metals by maize, additional information was required. Results from greenhouse and field studies are discussed here providing information about 1) factors external to roots of one inbred affecting the accumulation of Cd by an adjacent different inbred; 2) maternal factors influencing the accumulation of Zn and Cd by hybrids; and 3) the constancy of predicted differential capacities of hybrids to accumulate Cd under field conditions.

Materials and Methods

Root Interaction Study--

Ipava silt loam (aquic arguidoll, fine, montmorillonite, mesic, pH 5.5) soil was collected from the end of a field that had received 202 mt/ha (dry weight equivalent) of liquid digested sewage sludge in four years. The soil was air-dried, ground, and mixed prior to subdividing into three-kg portions which were placed in plastic pots (20.3 cm diameter). Subsamples were taken for Cd analysis. Water was added to the pots until the soil was completely saturated, after which it was allowed to drain for three days. Four seeds of a single cross selected to take up high (H98 X B37) or low (B73 X R805) amounts of Cd were planted in each half of the surface area of a pot, until all possible pairs of different or the same inbreds (10) had been made. All pairs were replicated six times. All pots (12 rows) were rotated (2 rows to the north) on the greenhouse bench once each week and water was added as necessary to maintain soil moisture near field capacity. Ten days after planting, the number of plants was reduced to two. Thirty-four days after planting, one-half of the pots (three replications) were randomly selected from which whole plants were harvested. Three leaves adjacent to ear nodes, were harvested 89 days after planting from each plant growing in the remaining 30 pots. All samples were prepared and analyzed for Cd concentrations according to methods described below for the field study.

Maternal Influence Study--

Five inbreds were selected from the screening study that had shown a low to high propensity for accumulating Cd and another five were selected for their range in capacities to take up Zn. Using the selected inbreds, reciprocal crosses were made between those that accumulated high and low amounts of Cd. Two of the hybrids were crosses of related inbreds (B37 X B73 and H98 X Oh545) and two were unrelated (B37 X R805 and H98 X B73) crosses. Analogous reciprocal crosses were made between related and unrelated inbreds that accumulated high and low amounts of Zn. Related crosses were B37 X B14A and B37 X R802A and unrelated crosses were A619 X H98 and A619 X B14A. These crosses were made in the University of Illinois South Farm corn breeding nursery. Ten seeds of each inbred and single-cross were planted in pots of sludge-amended Ipava silt loam soil as described above for the root interaction study. Each inbred and hybrid planting was replicated five and six times, respectively. Ten days after planting the number of plants per pot was reduced to four. Leaves from these four plants were harvested at six weeks from the date of planting. Daily maintenance was identical to that previously described for the root interaction study. All soil and plant tissue samples were analyzed for Cd and Zn concentrations by methods described below for the field study.

Field Study--

Single-crosses Mo17 X H98 and Oh545 X B73 were selected as high and low Cd accumulators, respectively, and planted each year in split-plots of Blount silt loam (Aeric ochraqualf, fine, illitic, mesic, pH 7.4) soil with and without amendment with sewage sludge. The plots measuring 3.1 x 15 m were separated by a border area 3.1 m wide. The plots were formerly used to study changes in water quality and the first annual sludge application was made 9 years prior to the initiation of this study. Three replications for each of the three different sludge loading rates and a control (no sludge) were randomized within the study area. Liquid digested sludge from the Southwest Wastewater Treatment Plant in Chicago, Illinois, containing 1.5 to 3.5% suspended solids, was applied each year by furrow irrigation at approximate plot depths of 6.4, 12.7, and 25.4 mm. At each sludge application, control plots were irrigated with 25.4 mm of water. Successive applications were made when sufficient sludge moisture had been lost by infiltration and evaporation to permit additional sludge to be added to the maximum-sludge-treated (25.4 mm) plots. Thus, the frequency of sludge applications varied as a result of differences in climatic conditions during the growing season. All plots were fertilized with a broadcast application of KCl to supply 112 kg K/ha prior to plowing, ridging, and planting operations. Control plots also received 336 kg N/ha as NH_4NO_3 and 112 kg P/ha as triple superphosphate.

Seeds of either the Mo17 X H98 or Oh545 X B73 hybrid were hand-planted on ridges of randomly selected halves of plots at rates to provide populations of 60,000 plants/ha after thinning. When about 15% of the plants tasseled, the leaf adjacent to the ear node was collected from 10 plants in each split-plot, washed in distilled water, dried at 60°C, and ground to pass a 20-mesh screen. Subsamples of grain, hand-harvested from split-plots to determine yields, were dried and ground in the same manner as leaf samples. After grain harvest, 12 and 13 consecutive plants from the two center rows were harvested and weighed for a determination of stover yields. From the 25 plants, four plants were randomly selected, chopped into short segments with a corn knife, dried at 60°C to determine moisture contents, and ground to pass a 20-mesh screen. Leaf, grain and stover samples (2g) were digested in concentrated HNO_3 at 90°C, followed by $HClO_4$ at 200°C taken to dryness, dissolved in 0.1 N HNO_3 and analyzed for Ca, Mg, K, Fe, Mn, Cd, Cu, Cr, Ni, Pb, and Zn concentrations by atomic absorption spectrophotometry with appropriate background correction. Phosphorus concentrations were determined colorimetrically with the vanadomolybdate finish (Greweling, 1976) and N by a method described by Bremner (1965).

Soil samples were collected with stainless steel tubes to a depth of 76 cm from each plot following the first spring tillage operation and segmented into depths of 15 cm. After drying (60°C), crushing, and pulverizing to pass a 60-mesh screen, aliquots (0.5 g) were heated to 500°C for 24 hours, digested in concentrated HCl-HF, and dissolved in 1 N HCl for determining metal concentrations by atomic absorption spectrophotometry.

Results

The sludge-amended Ipava soil used for the greenhouse studies contained 57.4 ± 2.9 mg Cd/kg and 864 ± 25 mg Zn/kg. Thus, this soil contained about 115 and 10 times more Cd and Zn, respectively, than expected in a noncontaminated condition.

Inbreds H98 and B37 compared in the root interaction study accumulated significantly more Cd in whole plants (first harvest) and leaves (second harvest) than did inbreds B73 and R805, regardless of which inbred they were paired with in pots of sludge-amended Ipava (Table 31). Leaves collected near the tasseling period of growth contained significantly less Cd than did young whole plants, regardless of whether the inbreds accumulated low or high amounts of the metal. When R805 was paired with H98, it accumulated significantly more Cd in whole plants than when paired with either itself or B73. However, this was not the case for Cd concentrations in leaves from older plants of the same inbred pairs.

The wide differences in capacities to take up Cd and Zn by the corn inbreds used to investigate maternal effects may be seen in Table 32. Inbred B73 accumulated significantly less Cd in leaves than other inbreds, except R805. Reciprocal crosses between high Cd accumulators (B37 and H98) and low Cd accumulators (B73, R805, and Oh545) contained about the same concentrations of leaf-Cd. Regardless of which inbred was used as the female, Cd concentrations in leaves from single-crosses were intermediate to those in leaves from parent inbreds. Single-crosses containing B73 as one parent accumulated significantly less Cd in leaves than crosses containing either OH545 or R805. Relatively speaking, the differences in capacities of inbreds to accumulate Zn were not as wide as those selected as high and low Cd accumulators. Nevertheless, H99 accumulated significantly less and A619 significantly more Zn in leaves than other inbreds. Leaf-Zn concentrations were about the same in reciprocal crosses, showing the lack of maternal effects. Crosses containing inbred A619 had significantly more Zn in leaves than was found in those crosses composed of inbreds that accumulated lesser amounts of Zn. Where A619 was used as one of the parents, leaves of single-crosses contained Zn levels that were intermediate to those in leaves from parents. But, hybrids composed of parents that accumulated similar concentrations of Zn in leaves had leaf-Zn concentrations that were lower than those of either parent.

Table 31. Comparison of Cd concentrations in whole plants (1st harvest) and leaves (2nd harvest) of selected corn inbreds when paired with themselves or different inbreds in pots of soil amended with sewage sludge.

Primary Inbred	Harvest	Companion Inbred				
		H98	B37	B73	R805	LSD($P \leq 0.01$)
		-mg Cd/kg(dry wt) -				
H98	1st	90.9	86.0	94.7	80.0	n.s.[a]
	2nd	39.7	25.5	28.0	23.5	n.s.
B37	1st	102.0	100.0	90.7	90.8	n.s.
	2nd	64.1	58.0	67.2	51.6	n.s.
B73	1st	11.0	9.38	9.67	11.4	n.s.
	2nd	2.36	1.35	2.21	0.93	n.s.
R805	1st	16.8	15.3	12.6	12.5	3.0
	2nd	0.80	1.15	1.85	1.22	n.s.

a/ Not significantly different

Table 32. Concentrations (mg/kg dry weight) of Cd and Zn in leaves of corn inbreds and reciprocal crosses grown in pots of silt loam soil amended with sewage sludge. Inbreds listed first in single-crosses were used as females.

Leaf-Cd for Inbreds (n=5)

B37	H98	Oh545	R805	B73	LSD(P≤0.01)
84.34	81.02	21.20	15.43	11.68	6.24

Leaf Cd for Single-Crosses (N=6)

Unrelated			Related		
B37 X R805	R805 X B37	LSD	B37 X B73	B73 X B37	LSD
37.14	39.79	n.s.[a]	28.72	30.54	n.s.
H98 X B73	B73 X H98	LSD	H98 X Oh545	Oh545 X H98	LSD
31.59	33.28	n.s.	46.54	43.29	n.s.

Leaf-Zn for Inbreds (n=5)

A619	B37	B14A	R802A	H99	LSD(P≤0.01)
383.5	274.7	268.6	257.4	178.0	66.2

Leaf-Zn for Single-Crosses (n=6)

Unrelated			Related		
A619 X H99	H99 X A619	LSD	B37 X B14A	B14A X B37	LSD
306.5	324.3	n.s.	230.9	220.0	n.s.
A619 X B14A	B14A X A619	LSD	B37 X R802A	R802A X B37	LSD
313.0	312.8	n.s.	238.8	224.2	n.s.

a/ Not significantly different

When the field study was initiated in 1978, maximum-treated plots had already received a nine-year accumulation of 483 mt/ha of solids that contained 129 kg/ha of Cd and 2,275 kg/ha of Zn (Table 33). Other plots had received one-fourth and one-half of these amounts. During the first two years of the study an additional 115 mt/ha of sludge solids were applied on maximum-treated plots which concomitantly supplied 31 and 541 kg/ha of Cd and Zn, respectively. Sludge was also applied during the last year of the study, but the solids remained on the surface and it is known from other studies that their content of Cd and Zn would have affected levels in plant tissues to only a minor extent (Hinesly et al., 1981).

In Table 34, it can be seen that at the beginning of the study sludge applications had increased Cd contents in the soil surface (0-15 cm) from about 0.5 mg/kg to 6, 15, and 28 mg/kg in plots irrigated with sludge rates of 6.4, 12.7, and 25.4 mm, respectively. Correspondingly, soil-Zn contents had been increased from 72 mg/kg to 184, 348, and 528 mg/kg. Additional sludge applications during the study period increased soil contents of Cd and Zn, not only in the surface but to some extent in the 15-30 cm depth. Concentrations of these metals were not increased in soil at depths below 30 cm. A great deal of year to year variations in metal concentrations in soil were due to the small number of core samples (6 per plot) that were purposely kept at a minimum to preserve the integrity of the plots for a long-term study. Nevertheless, the data had sufficient precision to demonstrate the significant long-term increases of Cd and Zn in the soil. It is noteworthy that recovery of Cd and Zn from the soil relative to amounts applied (Table 34) is low. This phenomenon has been discussed in detail (Hinesly et al., 1981) and requires further investigation.

Grain and stover yields are shown in Table 35. During the first year hybrid Mo17 X H98 produced less grain on all sludge-treated as compared to control plots. Less grain was produced by Oh545 X B73 on one-fourth- and one-half-maximum-sludge-treated plots than on control plots. Rainfall was extremely low during the first growing season and, thus, it was expected that yields would be markedly higher on highly fertilized and water irrigated control plots. Apparently, the maximum liquid sludge applications alleviated the moisture stress conditions to some extent, but lesser sludge loading rates provided little relief from the condition. During the second year rainfall was adequate and well distributed for high corn yields and under these conditions yields from Mo17 X H98 were not increased by sludge treatments. But, in this one year the highest grain yields by Oh545 X B73 were on plots irrigated with the two higher rates of sludge. Rainfall was below normal in 1980, but grain yields by the two hybrids were not significantly affected by treatments. Grain yields of Oh545 X B73 were significantly higher in the second ($P \leq 0.01$) and third year ($P \leq 0.05$) when compared to those produced by Mo17 X H98.

The only difference in stover production associated with treatments occurred during the last year when Mo17 X H98 produced less on sludge-treated as compared to control plots. During each of the three years Oh545 X B73 produced more stover ($P \leq 0.05$) than the hybrid selected to take up high amounts of Cd.

Table 33. Annual amounts of liquid digested sewage sludge applied on maximum-treated Blount plots and accumulative amounts of solids, Cd, and Zn constituents of sludge.

	Liquid Sludge		Accumulative Constituents (dry wt)		
Year	Total Depth	Avg Solids Contents	Solids	Cd	Zn
	- -mm- -	- -%- -	-mt/ha-	- - - kg/ha- - -	
1969	99	1.56	19.3	5.2	122
1970	147	2.45	55.5	27.4	434
1971	373	2.78	160.2	51.4	898
1972	175	1.86	192.4	57.2	1033
1973	292	2.02	251.1	63.9	1257
1974	233	3.04	321.9	85.6	1607
1975	189	2.78	374.3	99.0	1852
1976	236	3.03	445.6	118.1	2125
1977	142	2.67	483.3	128.6	2275
1978	189	3.53	549.8	147.9	2537
1979	142	3.42	598.2	159.7	2716
1980	142	3.54	648.2	170.2	2891

Table 34. Concentrations of Cd and Zn in Blount silt loam plots, with and without annual sewage sludge applications. Sludge applications were initiated in 1969.

Depth cm	Year	Cadmium 0	Cadmium 6.4	Cadmium 12.7	Cadmium 25.4	Cadmium LSD	Zinc 0	Zinc 6.4	Zinc 12.7	Zinc 25.4	Zinc LSD
		Sludge Irrigation Rates (mm)									
		-mg/kg (dry wt.)-									
0-15	1971	0.74	2.52	4.59	8.47	3.87**	73	106	174	241	55**
	1972	<0.25	1.58	2.62	5.90	3.49**	72	103	122	220	30**
	1973	0.27	3.78	6.00	11.4	3.28**	67	113	166	270	94**
	1974	0.57	3.78	6.13	11.8	1.33**	72	147	196	308	56**
	1975	<0.25	3.60	8.72	21.1	5.60**	69	150	250	432	91**
	1976	0.32	6.25	12.7	20.6	5.75**	68	188	326	454	75**
	1977	0.53	6.55	15.2	27.8	3.63**	72	184	348	528	38**
	1978	0.47	7.77	17.7	28.3	6.29**	77	216	385	602	125**
	1979	0.44	7.17	17.6	30.1	5.66**	73	200	390	606	94**
	1980	0.72	8.97	14.3	26.3	4.87	79	268	321	537	127**
15-30	1973	<0.25	<0.25	<0.25	<0.25	n.s.a/	65	68	68	76	94**
	1974	<0.25	<0.25	<0.25	<0.25	n.s.	70	94	80	110	127**
	1975	0.38	0.52	0.46	0.56	n.s.	67	75	73	84	10*
	1976	<0.25	<0.25	0.38	0.37	n.s.	63	79	75	71	n.s.
	1977	<0.25	<0.25	0.67	0.37	n.s.	66	73	85	86	13**
	1978	<0.25	<0.25	1.39	0.50	n.s.	68	81	94	70	23**
	1979	<0.25	0.47	0.47	1.46	0.75**	58	71	65	86	14**
	1980	<0.25	0.53	0.67	0.61	n.s.	79	82	77	84	n.s.

** Significantly different at $P \leq 0.01$
* Not Significantly different at $P \leq 0.05$
a/ Not significantly different

Table 35. Grain (adjusted to 15.5% moisture) and stover (dry wt.) yields produced by two corn hybrids on split-plots of Blount silt loam with and without sewage sludge.

	Mo17 X H98					Oh545 X B73				
	Sludge Irrigation Rates (mm)									
Year	0	6.4	12.7	25.4	LSD	0	6.4	12.7	25.4	LSD
	mt/ha									
	Grain									
1978	8.34	6.34	6.64	7.38	1.48**	8.62	6.02	6.51	8.42	0.94**
1979	9.26	10.1	10.3	8.70	n.s.	10.9	11.6	12.7	12.9	1.32*
1980	9.02	9.08	8.56	7.76	n.s.	10.1	10.0	9.48	9.30	n.s.a/
	Stover									
1978	6.35	4.95	3.92	5.73	n.s.	6.59	5.82	6.78	6.54	n.s.
1979	7.72	6.81	7.29	8.54	n.s.	7.97	8.04	8.87	8.61	n.s.
1980	9.31	6.34	7.12	7.84	0.36*	9.52	7.99	9.73	9.89	n.s.

** Significantly different at $P \leq 0.01$
* Significantly different at $P \leq 0.05$
a/ Not significantly different

Cadmium concentrations in leaves, grain, and stover of the high (Mo17 X H98) and low (Oh545 X B73) Cd accumulating hybrids are exhibited in Table 36. Cadmium concentrations were increased in all tissues of both hybrids with increasingly higher sludge loading rates, except in grain of Oh545 X B73 during the last year. For all treatments and years grain from Oh545 X B73 contained less than detectable levels (0.062 mg/kg) of Cd, except that from maximum-sludge-treated plots. To statistically analyze these data for grain-Cd concentrations, less than detectable values were scored as one-half the detectable limit. Sludge applications made during the study period may have caused successively higher concentrations of the metals in stover produced by both Mo17 X H98 ($P \leq 0.01$) and Oh545 X B73 ($P \leq 0.05$). However, in several instances concentrations of the metals in stover from control plots also increased each year and thus some of the increases may have been in response to differences in climatic conditions (CAST, 1980).

It is noteworthy that Cd concentrations in all tissues of Mo17 X H98 greatly exceeded those in corresponding tissues of Oh545 X B73 in every year and for all sludge treatments including the controls. A 4x3x3x2 factorial analysis of variance using 4 sludge rates, 3 corn tissues, 3 years and 2 hybrids showed that hybrid was the most significant main effect ($P \leq .001$) in accounting for the variation in Cd concentration in corn tissue. It is also important to recognize that the grain-Cd concentration in the low (Oh545 X B73) accumulator grown on the maximum-sludge-treated soils was only slightly greater than that in the high (Mo17 X H98) accumulator when it was grown on control plots with very low soil-Cd concentrations.

Concentrations of Zn in leaves, grain, and stover of both hybrids are presented in Table 37. Higher sludge applications caused significantly higher Zn concentrations within each year of all tissues of both hybrids. Only stover produced by Mo17 X H98 showed a significant ($P \leq 0.05$) increase in Zn concentration from year to year in response to accumulative sludge-borne Zn applied during the study, although a trend for higher Zn contents in Oh545 X B73 stover with additional annual applications of sludge-borne Zn can also be seen.

The two hybrids were selected to be different only in their capacities to take up Cd and, for the most part, this was accomplished. However, during the first and second years Mo17 X H98 on sludge-treated plots accumulated more Zn in leaves and less in stover ($P \leq 0.01$) than did Oh545 X B73. Grain-Zn concentrations were never significantly different for the two hybrids. During all years, Mo17 X H98 had higher contents of Fe and Cu in grain, lower contents of Mn in grain, higher contents of K and lower contents of Ca and Mg in leaves than similar tissues from Oh545 X B73 (data not shown).

Conclusions

Except for Fe, we are unaware of results showing changes in uptake of metals by one genotype in response to stimuli produced by the roots of another. Wallace et al. (1962) grew two soybean genotypes (*Glycine max* L.) that differed in their ability to accumulate Fe together in a solution culture containing a small quantity of calcareous soil. They found that the soybean variety that was inefficient in accumulating Fe caused a reduction in

Table 36. Concentrations (dry weight) of Cd in leaves, grain and stover of two corn hybrids grown on split-plots of Blount silt loam, with and without sewage sludge.

	Mo17 X H98					Oh545 X B73				
	Sludge Irrigation Rates (mm)									
Year	0	6.4	12.7	25.4	LSD	0	6.4	12.7	25.4	LSD
	mg/kg (dry wt.)									
	Leaves									
1978	0.852	8.27	12.6	20.2	6.0**	0.180	1.71	3.29	6.39	0.860**
1979	0.981	8.80	18.7	37.2	5.64*	0.198	1.51	4.44	13.0	4.74**
1980	0.927	9.52	21.3	42.0	6.42*	0.059	0.845	2.56	6.98	0.862**
	Grain									
1978	0.056	0.626	1.10	1.70	0.247**	<0.062	<0.062	<0.062	0.131	0.041**
1979	0.084	0.568	0.943	1.48	0.19**	<0.062	<0.062	<0.062	0.109	0.046*
1980	0.090	0.974	1.12	1.83	0.316**	<0.062	<0.062	<0.062	0.095	n.s.[a]
	Stover									
1978	0.753	5.78	10.8	24.6	4.52**	0.165	1.66	2.83	8.48	1.56**
1979	1.22	10.3	23.9	34.7	15.5**	0.271	1.82	4.18	11.5	3.74**
1980	1.45	14.2	24.9	44.4	12.4**	0.258	1.87	3.53	13.2	5.22**

** Significantly different at $P \leq 0.01$
* Significantly different at $P \leq 0.05$
a/ Not significantly different

Table 37. Concentrations (dry weight) of Zn in leaves, grain, and stover of two corn hybrids grown on split-plots of Blount silt loam, with and without sewage sludge.

	Mo17 X H95					Ch545 X B73				
	Sludge Irrigation Rates (mm)									
Year	0	6.4	12.7	25.4	LSD	0	6.4	12.7	25.4	LSD
	mg/kg (dry wt.)									
	Leaves									
1978	15.9	56.5	77.6	148	55.1**	14.5	39.9	61.3	118	34.0**
1979	19.3	51.6	88.5	173	14.0**	14.8	44.7	73.0	139	35.5**
1980	17.6	54.2	89.3	138	25.7**	13.7	49.2	76.0	130	24.2**
	Grain									
1978	16.6	29.9	31.4	42.8	5.70**	19.5	26.3	31.2	38.0	8.40**
1979	12.8	16.9	20.9	26.3	3.90**	12.8	21.0	31.2	27.1	9.24**
1980	19.2	26.7	26.0	33.7	7.84**	15.4	23.5	29.4	37.4	9.96**
	Stover									
1978	8.45	28.9	54.1	142	16.5**	6.12	32.9	79.3	192	54.9**
1979	7.44	34.9	88.0	160	15.3**	5.47	36.5	93.2	190	27.4**
1980	12.2	59.6	102	177	33.8**	10.4	51.7	109	204	25.5**

**Significantly different at $P \leq 0.01$

Fe uptake by the variety that was efficient. These results were confirmed by Elmstrom and Howard (1969) from plants grown in a growth chamber in nutrient solutions containing various levels of Fe.

If corn inbreds, having different inherited capacities to accumulate Cd from contaminated soils, can interact to change uptake patterns of each other when growing in close association, it was not obvious from the results of the greenhouse study (Table 31). Only where H98 and R805, a high- and low-Cd accumulator, respectively, were paired in pots of sludge-amended soil was a significant effect observed. Cadmium concentrations in whole plants (34 days after planting) of R805 were higher when it was paired with H98 as compared to concentrations when paired with itself or with B73, another low-Cd accumulator. However, Cd concentrations in leaves of R805 at the tasseling stage of growth were not different regardless of which inbred it was paired with. This finding in R805 during early growth may represent a real root interaction and deserves further investigation. However, since this effect was not general and occurred only during early stages of growth, we conclude that the results of a study designed to determine gene effects affecting genetic variations of Cd accumulations in corn would be biased very little, if at all, by the proximity of plants growing in field plots.

Reciprocal crosses between high-Cd and low-Cd and between high-Zn and low-Zn accumulator inbreds showed no evidence of a maternal effect on the uptake of metals. Leaves from single-crosses contained concentrations of Cd that were intermediate to those in leaves of their high- and low-Cd accumulator parents, regardless of whether or not the parents were related. Concentrations of Zn in leaves of single-crosses were also intermediate to those contained in leaves of unrelated parent inbreds that accumulated significantly different levels of the metals. But where leaves of related parent inbreds did not contain significantly different concentrations of Zn, concentrations of the metal were lower in leaves from their single-crosses. Lower Zn concentrations may have been due to a dilutive effect attributable to hybrid vigor. Dilution due to better growth of hybrids may complicate determination of the relative importance of different gene effects that control the accumulation of metals in corn plant tissues.

Results from the three year field study showed that the two commercially available hybrids selected for their different capacities to accumulate Cd were indeed different when grown on split plots where soils contained various levels of sludge-borne Cd. At the time of selection it was thought that the two hybrids would produce about the same grain yields. Even though the low-Cd accumulator produced more grain during the last two years, and more stover in all three years than the high-Cd accumulator the magnitude of the differences was small. Differences in yields were also observed on control plots and thus appeared to have no relationship to differences in capacities to accumulate Cd. At any rate the differences in yields were not enough to account for such large differences in Cd accumulations in the two hybrids by inferring a metal concentrating effect. Furthermore, from previous analysis of inbred parents of the two hybrids grown on sludge-treated plots, it was estimated that the two hybrids would accumulate similar quantities of other inorganic nutrient and non-nutrient elements, especially Zn. Although there were small differences in amounts of some elements accumulated in particular tissues of the two hybrids, only Cd in leaves of Mo17 X H98 exceeded the maximum tolerable concentrations discussed by Allaway (1968) and Melsted (1973). However, there were no overt symptoms of Cd toxicity in either hybrid and no reason to expect that differences in yields were due to anything more than inherent differences in growth potential.

Differences in accumulations of Cd by the two hybrids did not affect Zn uptake. In two of the three years one of the hybrids accumulated more Zn in leaves and less in stover than the other, but the magnitude of these differences was small relative to amounts accumulated in these tissues by both hybrids growing on sludge-treated soils. In the presence of an abundantly available supply of both Cd and Zn, the uptake of these metals appears to be independent of each other.

For those concerned about enhanced levels of Cd in food chains, it is noteworthy that grain-Cd concentrations of Oh545 X B73 growing on maximum-sludge-treated plots were significantly higher than those of Mo17 X H98 growing on control plots only during the first year. Furthermore, Cd concentrations in grain from Oh545 X B73 never exceeded the upper range of 0.294 mg/kg found in corn grain of unidentified hybrids grown on conventionally fertilized soils in rural areas of Illinois (Pietz et al., 1978). It is likely that other combinations of parent inbreds could have been selected to produce a hybrid not commercially available that would have minimized Cd accumulations in grain produced on sludge-amended soils to levels not exceeding the mean concentrations of 0.037 mg/kg found in corn grain produced on unadulterated soils. One such hybrid might be B73 X R805.

EFFECT OF SOIL CATION EXCHANGE CAPACITY ON THE UPTAKE OF CADMIUM BY CORN (*Zea mays* L.)

Introduction

For sewage sludges containing more than 2 mg Cd kg of sludge, the U.S. EPA (1979) regulated maximum accumulative applications of sludge-borne Cd on soils with background pH values of 6.5 or higher according to cation exchange capacities (CEC). Where soil cation exchange capacities are less than 5, in the range of 5 to 15, and higher than 15 meq/100 g, maximum permitted accumulative loading rates were, respectively, fixed at 5, 10, and 20 kg/ha of sludge-borne Cd. They stated that "several studies have demonstrated the inverse relationship between CEC and plant uptake of Cd". However, it appears that most researchers have attempted to demonstrate the relationship by adding soluble Cd salts to soils.

John et al. (1972) added 50 mg Cd as $CdCl_2$ to pots containing 500 g of each of 30 different soil types. Using radish (*Raphanus sativus* L.) and lettuce (*Lactuca sativa* L.) as test plants and linear regression analysis of results, he concluded that the most important single factor associated with lower levels of Cd in radish plant parts was the capacity of soils to adsorb the metal. Oxidizable organic matter contents of soils contributed to their capacities to adsorb and therefore affected Cd concentrations in plants inversely. Where the original organic matter of a clay soil was removed by oxidation (H_2O_2 treatment) and replaced with muck to obtain different levels of CEC, Haghiri (1974) added constant amounts of Cd, as $CdCl_2$, in one study and variable amounts in another to maintain a constant ratio of applied Cd to CEC. He grew oats (Avena sativa L.) for 4 weeks in pots to determine Cd uptake from the various soil mixtures. He concluded that the decreased concentrations of Cd found with higher levels of added organic matter were predominantly due to its CEC. That is, the Cd retaining power of organic matter was due to its CEC rather than its capacity to chelate the metal. However, as Latterell et al. (1976) pointed out, when dry weight yields and concentrations of Cd in oats, as reported by Haghiri (1974), were multiplied, they showed a rather constant uptake of Cd regardless of soil CEC. Miller et al. (1976) grew soybeans (Glycine max L.) for 4 weeks in a $CdCl_2$ rate experiment in pots of 9 different soils selected to obtain a relatively wide range of CEC, pH, and available P levels. Where soils contained 1, 10, and 100 mg Cd/kg of soil, they found that Cd contents of plants were negatively correlated (significant only at the 5% probability level) with CEC only for soils containing 10 mg Cd/kg. Latterell et al. (1976) diluted Waukegan silt loam soil with sand to obtain CEC's that ranged from 5.2 to 18.5 meq/100 g and amended the mixture with digested sludge containing 2 mg Cd/kg of sludge at rates equivalent to 0, 23.3, and 46.7 mt/ha (dry weight). Dry matter yields and Cd concentrations in 30-day old soybean seedlings were unaffected by differences in CEC. Mean Cd concentrations in seedlings were slightly increased by the 23.3 mt/ha sludge application, but doubling the loading rate did not cause further increases. Sims and Boswell (1978) mixed a "secondary industrial sewage sludge" with a Cecil loam soil (Typic Hapludult) to produce mixtures containing 0, 2.5, 5, and 10% sludge. They superimposed additions of 0, 5, and 10% calcium saturated bentonite over the sludge treatments in a 3 x 4 complete factorial pot study. Mixtures containing 5 and 10% bentonite had initial CEC of 13.2 and 20.4 meq/100 g, respectively, as compared to 7.4 meq/100 g in the untreated control soil. Also, successively higher loading rates of bentonite increased soil pH to 6.0 and 6.6 as compared to 5.2 in untreated soil. Sludge additions did not significantly alter the CEC and soil pH. They concluded that CEC and pH effects from added bentonite could not be separated. Much of the discussion of results concerned explanation of an observed CEC reduction that occurred in bentonite mixtures between the initial and post-harvest analyses. The decrease in CEC with time was directly proportional to amounts of bentonite added.

In the above studies, soil cation exchange capacity was generally determined by the ammonium acetate method (Chapman, 1965), suggesting that all exchangeable Cd was held by the same mechanisms. Because of the conflicting results reported by these investigators, it appears that the capacity of soils to adsorb Cd and restrict its uptake by plants is complex and not controlled directly by CEC. It was the purpose of this study to determine whether plant uptake of Cd is less when the source is sludge-derived than when the source is the soluble $CdCl_2$ salt and how plant uptake might be altered by differences in soil CEC.

Methods and Materials

The B_1 horizon (28 to 41 cm) of an Ava soil (Typic Fragiudalf), the Ap horizon of a Maumee soil (Typic Haplaquoll), and the mixed A_1 and B_1 horizons

(0 to 30 cm) of a Plainfield soil (Typic Udipsamment) were collected to provide a wide range of organic-C contents and CEC's. Results of the subsequent textural analysis, performed on the bulk sample collected from an area mapped as the Maumee series in Kankakee County, Illinois, indicated that this soil was outside of the range for the Maumee series and was actually a mapping inclusion. Important characteristics of soil materials used in this study are presented in Table 38. Maumee Ap had a high CEC that was mainly due to its organic matter content. Ava B_1 had a moderately high CEC that was due mainly to its content of clay and hydrous oxides of Fe and Al. Plainfield has a low CEC, because it contained low concentrations of both organic matter and clay. Ava was used in the study with and without additions of Plainfield to obtain CEC of about 15.9, 10.6 and 5.3 meq/100g. Plainfield was also added to Maumee and to half and half mixtures of Ava and Maumee to obtain a similar range of CEC's. Mixtures of screened (7 mesh) and air-dried soil materials were made in a twin shell soil blender. To 12 kg of Ava and each of 8 different soil mixtures, either air-dried and ground (10 mesh) digested sewage sludge or a solution of 0.003 $\underline{M}$ $CdCl_2$ (applied by atomization) was added at rates (0.535 kg and 0.2477 g, respectively) required to attain a total Cd concentration of 10 mg/kg (dry weight) in soil or soil mixtures. The sludge had an organic-C content of 12.8% (dry weight), CEC of 24 meq/100 g, pH of 6.0, and Cd concentration of 238 mg/kg. Sludge was added at the rate of 0.535 kg to supply a total Cd concentration of 10 mg/kg in 12 kg of soil or soil mixture. Each of the 12-kg quantities of Ava or soil mixtures were then subdivided into three-kg portions and each portion placed into one of 4 plastic pots (20.3 cm diameter). Water was added to the pots until the soil was completely saturated. After drainage and evaporation had decreased soil water contents to approximately field capacity, small cores of soil were extracted with a probe (13 mm diameter) for analysis and eight evenly distributed corn seeds of the single-cross Mo17 x H98 were planted in each pot. The pots were rotated once each week on the greenhouse bench. The experiment was conducted under natural sunlight supplemented with mercury-vapor lighting to achieve a constant photo-period of L:D = 16:8. Water was added at the beginning and nutrient solution (commercial, 23-19-17) at the end of each week to replenish soil moisture contents. Ten days after planting, the number of plants was reduced to six per pot. The first harvest of three

Table 38. Characteristics of experimental soils.

Soil	Particle Size Distribution			Organic-C	CEC	pH
	Sand	Silt	Clay			
	------------%------------			----%----	meq/100 g	units
Ava B_1	11.9	60.4	27.7	0.24	15.9	4.6
Maumee Ap	30.9	53.5	15.6	16.3	58.9	7.2
Plainfield	93.9	3.4	2.7	0.25	1.4	5.3

above-ground whole plants was made three weeks after planting. During the first harvest the top-most leaves of the remaining three plants in each pot were marked, so that when they were harvested at the end of seven weeks from planting, new and old growth were separated for Cd analysis.

After final harvest, soil core samples were again taken from each pot and analyzed separately for organic-C contents, CEC, Cd and pH. In contrast, samples collected initially from treatment replications were combined for determining these 4 soil parameters.

Soil and sludge parameters were determined as follows: mechanical analysis by the pipette method (Day, 1965); organic-C by the Walkley-Black method (Allison, 1965); CEC by the ammonium saturation method (Chapman, 1965) and pH in a 1:1 soil or sludge to distilled water slurry employing a glass electrode pH meter. After drying (60°C), crushing, and pulverizing (60 mesh screen), soil samples (0.5 g) were heated to 500°C for 24 hours, digested in concentrated HCL-HF and dissolved in 1 N HCl for determining total Cd concentrations, using atomic absorption spectrophotometry with background correction.

Plant samples were washed in distilled water immediately after cutting, dried at 60°C, and ground in a Wiley mill to pass a 20-mesh screen. Subsamples (2g) were wet-ashed in concentrated HNO_3 at 90°C, taken to dryness, and dissolved in 1 N HNO_3 for determining Cd concentration by atomic absorption spectrophotometry.

Results and Discussion

Organic carbon contents, CEC's, Cd concentrations, and pH levels of sludge- and $CdCl_2$-treated Ava B_1 and soil mixtures prior to planting and after harvest of plants are shown in Table 39. Except for Ava B_1, organic-C contents were changed very little by sludge additions. Maumee Ap contained such a high organic-C content (16.3%) that the relatively small amounts (0.6% dry weight of soils) added as air-dried sludge could not be detected in mixtures that contained this particular soil. Due to the inherent heterogeneity of soils, sampling errors were evidently too high to detect the small decompositional losses of sludge-borne organic-C that may have occurred during the 7-week study period. In consideration of soil heterogeneity, the CEC's were close to those anticipated for soil mixtures. Although sludge no doubt contributed to the CEC of sludge-treated soils, it was not a measurable effect. No appreciable change in CEC's was observed for either sludge or $CdCl_2$ treatments during the course of the experiment. Total Cd concentrations in soils were near the proposed level of 10 mg/kg, except for sludge-treated Ava. Since the organic-C contents and CEC for sludge-treated Ava were within expected ranges of values, this unforseen result was probably due to the nonuniform distribution of Cd in sludge. Differences of Cd concentrations in soil samples collected prior to planting and those collected after harvest were due to variability associated with sampling and analysis. The highest amounts of Cd extracted by plants were from the low CEC, Ava-Plainfield mixture treated with $CdCl_2$. About 2.1% of the total Cd contained in this mixture was removed as a constituent of harvested plants. The amount removed by plants was too low to detect in the soils due to the soil variability.

Table 39. Initial and post-harvest (P-H) characteristics of soil mixtsures amended with either sewage sludge or $CdCl_2$.

Soil Mixture[a]	Treatment	Organic-C Initial	Organic-C P-H, SD[b]	CEC Initial	CEC P-H, SD[b]	Soil-Cd Initial	Soil-Cd P-H, SD[b]	pH Initial	pH P-H, SD[b]
		--------%--------		----meq/100g----		-----mg/kg-----			
Ava	sludge	0.70	1.10±0.15	17.7	16.4±0.6	19.6	20.6±1.0	5.0	4.8 0.1
Ava-Plainfield	sludge	0.69	0.84±0.19	9.4	11.1±0.7	13.4	18.2±1.3	5.2	5.2 0.1
Ava-Plainfield	sludge	0.43	0.78±0.09	3.6	5.4±2.1	8.0	12.6±1.3	5.5	5.5 0.1
Ava	$CdCl_2$	0.24	0.37±0.08	16.1	15.4±0.5	10.5	10.2±1.5	3.9	3.7 0.1
Ava-Plainfield	$CdCl_2$	0.17	0.35±0.22	8.6	9.9±0.6	9.2	10.3±1.9	4.2	3.7 0.03
Ava-Plainfield	$CdCl_2$	0.17	0.33±0.07	3.9	4.5±0.3	11.6	7.8±1.3	4.4	4.1 0.03
Maumee-Ava-Pla.	sludge	3.34	3.06±0.31	18.2	18.4±0.9	12.2	15.4±1.0	6.1	5.6 0.1
Maumee-Ava-Pla.	sludge	1.76	2.03±0.26	10.2	11.6±0.2	10.7	11.7±1.5	5.9	5.7 0.1
Maumee-Ava-Pla.	sludge	0.89	0.87±0.17	5.4	5.6±0.6	9.0	9.8±1.5	5.8	5.7 0.1
Maumee-Ava-Pla.	$CdCl_2$	3.86	2.51±0.25	18.1	17.2±1.0	11.9	10.2±0.5	5.7	4.9 0.2
Maumee-Ava-Pla.	$CdCl_2$	1.79	1.72±0.09	10.9	11.4±0.1	11.4	10.6±1.4	5.8	5.1 0.2
Maumee-Ava-Pla.	$CdCl_2$	0.64	0.64±0.04	5.8	5.3±0.4	10.0	7.5±1.5	5.8	5.0 0.04
Maumee-Pla.	sludge	3.83	3.79±0.37	16.2	15.1±1.0	9.3	11.7±0.4	6.6	6.0 0.1
Maumee-Pla.	sludge	2.53	2.08±0.20	10.4	10.2±1.3	9.5	11.2±0.3	6.5	6.1 0.1
Maumee-Pla.	sludge	1.19	1.12±0.17	6.2	5.6±0.6	7.0	10.2±2.0	6.3	6.0 0.1
Maumee-Pla.	$CdCl_2$	3.94	3.32±0.11	17.7	16.6±1.5	12.8	8.9±1.3	6.6	6.2 0.1
Maumee-Pla.	$CdCl_2$	2.79	2.37±0.13	11.3	9.6±0.4	13.3	7.6±1.4	6.6	6.1 0.1
Maumee-Pla.	$CdCl_2$	1.06	0.87±0.22	3.7	5.2±0.6	9.8	6.8±1.1	6.4	5.6 0.1

[a] Each set of three soils represents three different dilutions with Plainfield Sand estimated to yield CEC levels of approximately 5.3, 10.6 and 15.9 meq/100 g.

[b] SD = Standard Deviation

The Ava soil pH (Tables 38 and 39) was increased by sludge and decreased by $CdCl_2$ treatments. Sludge was more and $CdCl_2$ less effective in changing the pH with higher dilutions of Ava B_1 with Plainfield. Ava and Ava-Plainfield mixtures had lower pH's than other mixtures. At the two highest CEC's, Maumee-Plainfield mixture had higher pH values than other mixtures. However, except for Ava and Ava-Plainfield mixtures, pHlevels within the range of low to high CEC's were not different nor were they different between the sludge and $CdCl_2$ treatments.

Data presented in Figure 5 clearly depicts the presence of an inverse relationship between Cd uptake by corn plants and soil CEC where the source of Cd was a soluble salt, but not where it was added as a constituent of sewage sludge. The high F ratio, as shown in the analysis of variance for whole plant data (Table 40), leaves little doubt that the main difference in Cd uptake was due to source. The second most important factor which affected Cd uptake was differences in soil mixtures. Soil CEC exerted the least influence on Cd uptake. All interaction effects were highly significant ($P \leq 0.01$). The most important interaction was between Cd source and soil mixture. When single degree of freedom comparisons were made (Table 40), it was found that both the linear and quadratic components for regression of Cd uptake on CEC were highly significant ($P \leq 0.01$) for $CdCl_2$ source, except the quadratic component for the Maumee-Ava mixtures. This analysis confirms that sludge controls plant uptake of Cd more than does CEC. Uptake of Cd from Ava and Ava mixtures with Plainfield was significantly ($P \leq 0.01$) higher than that from Maumee mixtures with Plainfield at all levels of CEC when the source of Cd was $CdCl_2$. But, when the Cd was sludge-derived, uptake was significantly higher ($P \leq 0.05$) from Ava than Maumee mixtures only at the highest level of CEC. However, this difference between sludge-treated Ava and Maumee mixture was undoubtedly due to the anomalously high Cd concentration in Ava (Table 39) as discussed previously. Cadmium concentrations in whole plants from the Ava-Maumee mixtures, amended with $CdCl_2$ was not significantly different than means amounts calculated from the individual Ava and Maumee series, except for mixtures having low CEC. This result can be confirmed visually from an examination of Figure 5.

Since soil pH and organic matter were both higher according to the order Maumee > Maumee-Ava > Ava mixtures, their effects on Cd uptake from $CdCl_2$ additions cannot be separated and evaluated from these results. However, in studies discussed previously in this report where repeated applications of digested sludge were made on plots of an acid silt loam soil and calcareous strip mine spoil material for periods of 12 and 7 years, respectively, Cd uptake by corn was considerably higher on spoil and continued to increase with repeated sludge applications. This was true even though pH was much higher in the calcareous spoil than that of the acid silt loam. If pH exhibited a dominant influence on Cd uptake, the sludge-amended Ava series should have produced plants with higher Cd levels than all other soil mixtures, except the Ava series amended with $CdCl_2$. However, Cd uptake from the sludge-amended Ava series was not significantly different, with one exception, from the Maumee series that had the highest pH, indicating that sludge properties may be more important. The exception, as previously explained, was caused by a higher soil-Cd concentration.

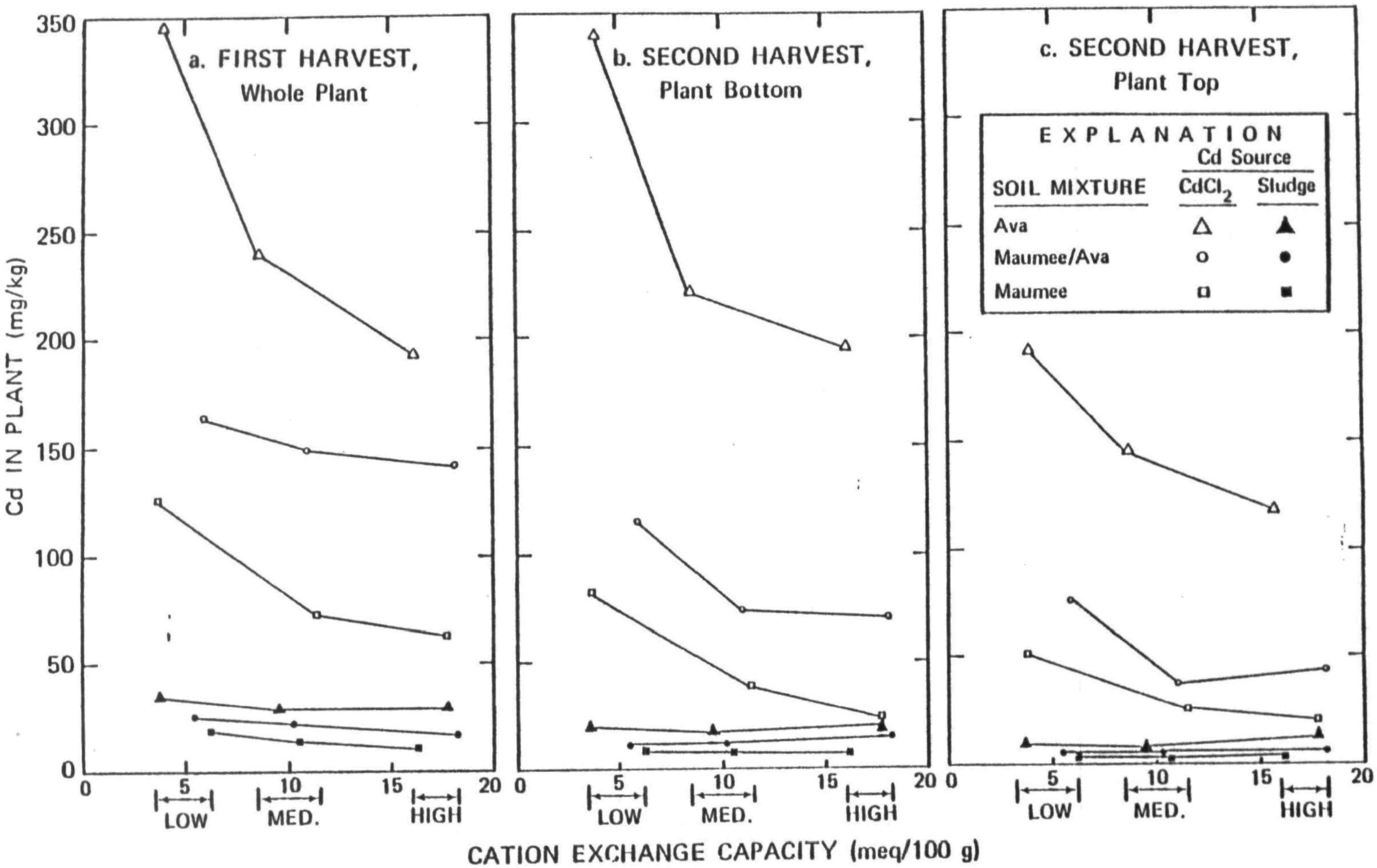

Figure 5. Concentrations of Cd in corn tissue grown on soil mix combinations resulting in 3 levels of CEC, containing 10 mg/kg of Cd derived from $CdCl_2$ or sewage sludge.

Table 40. Analysis of variance for Cd concentrations in plants (mg/kg) harvested three weeks after planting.

Source of Variation	df	SS	MS	F
A = CEC	2	24,247.93	12,123.97	101.19**
B = soil mixture	2	109,573.52	54,786.76	457.28**
C = Cd source	1	374,186.03	374,186.03	3,123.19**
AB	4	9,087.31	2,271.83	18.96**
AC	2	16,776.34	8,388.17	70.01**
BC	2	75,332.71	37,666.35	314.39**
ABC	4	10,166.09	2,541.52	21.21**
Error	54	6,469.68	119.81	
Total	71	625,639.61		

Significance levels for single degree of freedom comparisons

Comparison	Cd Source	
	Sludge	$CdCl_2$
CEC_L (linear) within Ava	n.s.	**
CEC_Q (quadratic) within Ava	n.s.	**
CEC_L within M/A (Maumee/Ava)	n.s.	**
CEC_Q within M/A	n.s.	n.s.
CEC_L within Maumee	n.s.	**
CEC_Q within Maumee	n.s.	**
[Ava vs. Maumee] within CEC_{Lo}	n.s.	**
[M/A vs. mean (Ava + Maumee)] within CEC_{Lo}	n.s.	**
[Ava vs. Maumee] within CEC_M	n.s.	**
[M/A vs. mean (Ava + Maumee)] within CEC_M	n.s.	n.s.
[Ava vs. Maumee] within CEC_H	*	**
[M/A vs. mean (Ava + Maumee)] within CEC_H	n.s.	n.s.

*, ** = significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = non-significant F-ratio.

An analysis of variance was performed on the data presented in Figures 5b and 5c for Cd concentrations in the bottom and top portions of plants harvested seven weeks after planting. Results of the data analysis were similar to those for the first cutting (Table 40) except that concentrations of Cd in plants from Maumee-Ava mixtures were significantly different from the mean concentrations calculated from individual series of Ava and Maumee, at all CEC levels. The data plotted in Figures 5a and 5b showed that Cd concentrations in the bottom portion of plants from the $CdCl_2$ treated Ava series remained about the same as that of whole plants from the first harvest. Because the first growth on the $CdCl_2$ treated Ava series showed symptoms of severe Cd toxicity, further growth of the bottom portion of these plants was almost nil. Cadmium toxicity affected further growth of the bottom portion of plants between the first and second harvest on $CdCl_2$ treated Ava-Maumee and Maumee mixtures to a lesser extent than those on the Ava series so that Cd concentrations may have decreased as a result of the diluting effect of additional growth on these two. Concentrations of Cd in the new growth material produced during the interval between the first and second harvest, were less on all soil mixtures than in plants at the first harvest (Figure 5, a and c). This may have been due to decreasing availability of Cd in soil mixtures and/or decreasing uptake of Cd with plant age.

Toxicity symptoms of chlorotic streaking and stunting were visually evident for the $CdCl_2$ treatments; symptoms were less severe according to the order Ava, Ava-Maumee, and Maumee series. Where Cd was supplied as a constituent of sludge, no overt symptoms of Cd toxicity were observed in plants grown on any of the different soil mixtures. The single-cross (Mo17 x H98) used in this study was selected for its inherited capacity to accumulate high concentrations of Cd without showing toxicity symptoms on a soil that contained about 3-fold higher concentrations of sludge-borne Cd than used in this study (Hinesly et al., 1981a). At the approximately 10 mg/kg of soil-Cd used in this study, differential Cd uptake was probably due to factors external to plant roots affecting availability of the metal, rather than plant physiological processes regulating the absorption and translocation of Cd.

Mean weights (dry) of plants grown for 3-weeks on the several soil mixtures treated with $CdCl_2$ and sludge are shown in Figure 6a along with mean amounts of Cd accumulated per plant (Figure 6b). An analysis of variance showed differences in weights were due mainly to Cd source and to a lesser extent by soil mixture. But, soil CEC and interaction effects were not significant. Plants appeared to make normal growth on all sludge-treated soil mixtures, while those on all $CdCl_2$ treated mixtures were stunted and showed typical Cd toxicity symptoms. The $CdCl_2$ treatment affected plant growth to a lesser extent (Figure 6a) on Maumee than on Ava mixtures.

The analysis of variance for mean total amounts of Cd per 3-week old plants is presented in Table 41. By order of listing, differential uptake of Cd was affected by Cd source, soil mixture, and soil CEC. Since all interactions were significant, single degree of freedom comparisons were made. These showed that total amounts of Cd accumulated per plant were not different where the metal source was sludge, but did differ in response to these parameters where $CdCl_2$ was the source (Table 41 and Figure 6b). On the $CdCl_2$ treated Ava and Maumee series total amounts of Cd accumulated decreased in a linear fashion as CEC increased. At all levels of CEC, plants accumulated about 2-fold higher total amounts of Cd when grown on the Ava series treated with $CdCl_2$ as compared to amounts from Maumee treated with equivalent amounts of the salt. Except at low CEC, plants grown for 3 weeks on $CdCl_2$-treated Maumee-Ava mixtures accumulated less total Cd than would have been predicted from the average amounts accumulated from the individual Ava and Maumee series.

Where corn plants were grown for 7 weeks, average weights of plants were significantly affected to the greatest extent in order of Cd source, soil mixture, and CEC (Table 42 and Figure 7a). All interactions were significant. Single degree of freedom comparison showed that plant weight increased with increased CEC on the $CdCl_2$ treated Maumee-Ava and Maumee series, but not on the $CdCl_2$-treated Ava. Plant weights were unaffected by differences in CEC's of soil mixtures where Cd was supplied as a constituent of sludge. Plant weights on different sludge-treated soil mixtures were not significantly different. But, on the $CdCl_2$-treated Ava and Maumee series, plant weights were significantly higher on the latter at all CEC levels, except the lowest.

Total amounts of Cd accumulated per plant at the end of 7 weeks of growth on sludge and $CdCl_2$ treated soil mixtures are shown in Figure 7b and the analysis of variance for these data is presented in Table 43. All three main parameters and their interactions significantly influenced the total amounts of Cd accumulated per plant. The significance of CEC and interaction effects that influenced total Cd accumulations in 7-week old plants were contrary to results from 3-week old plants. For older plants grown on $CdCl_2$-treated soil mixtures total amounts of Cd accumulated per plant decreased as soil CEC increased, but total accumulations of sludge-borne Cd were unaffected by CEC. At all CEC levels plants grown on the Ava series accumulated significantly more total Cd than those on the Maumee series for both sources of Cd. However, amounts accumulated were markedly less on all sludge-treated soil mixtures than they were for $CdCl_2$ treatments, except at the high CEC level for $CdCl_2$-treated Maumee and sludge-treated Ava, where amounts were about the same. This was probably a reflection of the anomalously high concentration of sludge-borne Cd in Ava, as discussed earlier. Total amounts of Cd accumulated by corn on $CdCl_2$-treated Maumee-Ava mixtures were less than mean amounts calculated from results of similarly treated Ava and Maumee, except at the high CEC level. At all levels of CEC, total accumulated amounts of Cd from sludge-treated Maumee-Ava mixtures could have been predicted from the mean of amounts accumulated per plant on the sludge-treated Ava and Maumee series.

When considered separately, concentrations of Cd in and weights of plants grown on the three different series of sludge-amended soil mixtures were not significantly different, but were different when these data were used to calculate total amounts of Cd accumulated per plant. Except to increase CEC, it appeared that soil organic matter did not play a dominant role in controlling Cd accumulation by corn. In the $CdCl_2$-treated Ava, organic matter contents were affected very little by diluting with Plainfield (Table 38) even though amounts of Cd accumulated by 7-week old corn plants were reduced by about 32% (Figure 7b). In the $CdCl_2$-treated Maumee, organic matter contents were reduced by about 74% by diluting with Plainfield, but amounts of Cd accumulated

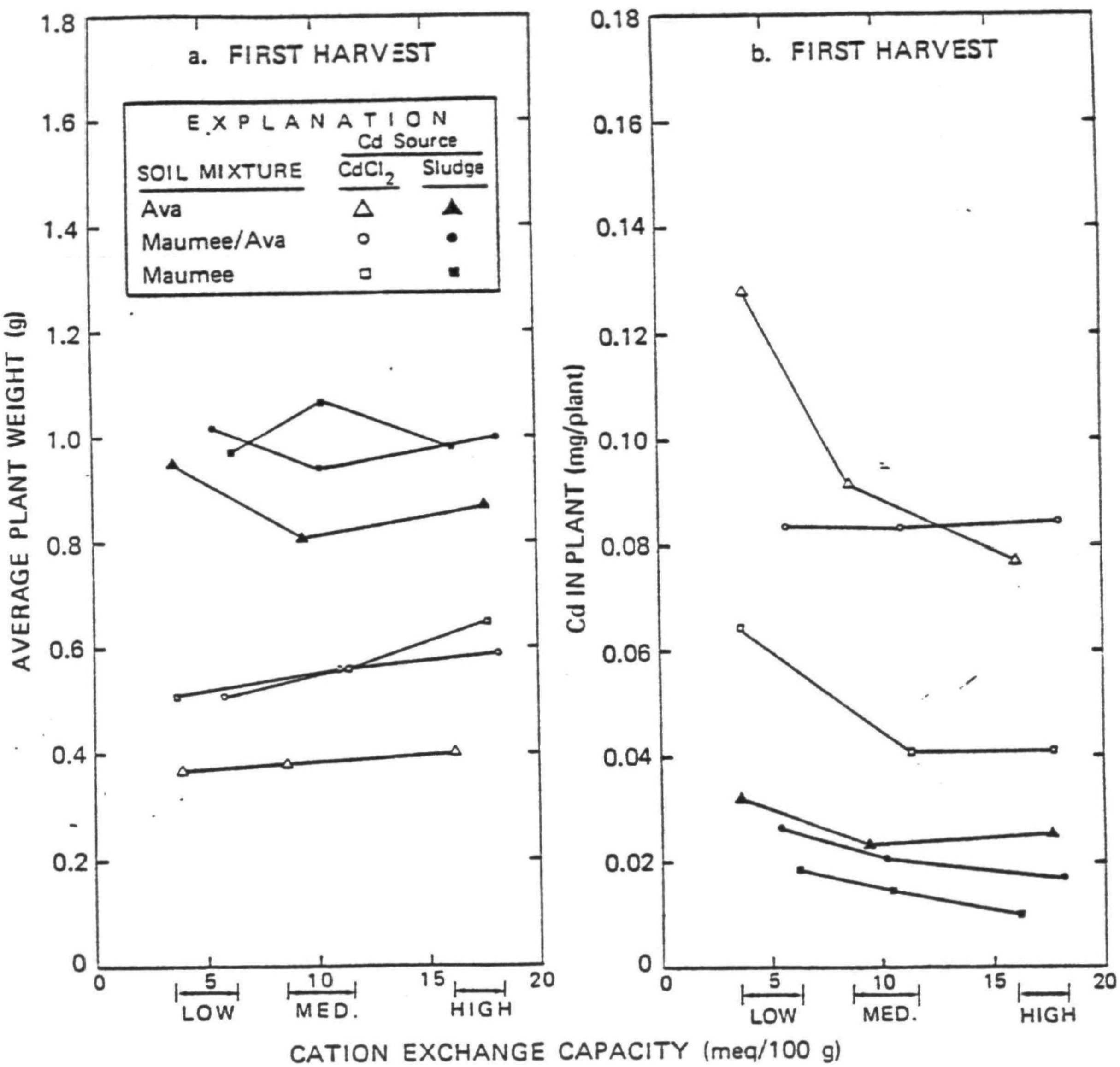

Figure 6. Mean weight (a) and amount of Cd accumulated (b) per plant for corn grown for 3 weeks on mixtures of soils combined to give 3 levels of CEC, containing 10 mg/kg of Cd derived from $CdCl_2$ or sewage sludge.

Table 41. Analysis of variance for mean total amounts (mg) of Cd accumulated per plant during the first three weeks.

Source of Variation	df	SS	MS	F
A = CEC	2	0.0036	0.0018	14.95**
B = soil mixture	2	0.0126	0.0063	51.83**
C = Cd source	1	0.0570	0.0570	468.75**
AB	4	0.0014	0.0003	2.81*
AC	2	0.0010	0.0005	3.92*
BC	2	0.0048	0.0024	19.84**
ABC	4	0.0016	0.0004	3.41*
Error	54	0.0066	0.0001	
Total	71	0.0886		

Significance levels for single degree of freedom comparisons

Comparison	Cd Source	
	Sludge	$CdCl_2$
CEC_L (linear) within Ava	n.s.	**
CEC_Q (quadratic) within Ava	n.s.	n.s.
CEC_L within M/A (Maumee/Ava)	n.s.	n.s.
CEC_Q within M/A	n.s.	n.s.
CEC_L within Maumee	n.s.	**
CEC_Q within Maumee	n.s.	n.s.
[Ava vs. Maumee] within CEC_{Lo}	n.s.	**
[M/A vs. mean (Ava + Maumee)] within CEC_{Lo}	n.s.	n.s.
[Ava vs. Maumee] within CEC_M	n.s.	**
[M/A vs. mean (Ava + Maumee)] within CEC_M	n.s.	*
[Ava vs. Maumee] within CEC_H	n.s.	**
[M/A vs. mean (Ava + Maumee)] within CEC_H	n.s.	**

*, ** = significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = non-significant F-ratio.

Table 42. Analysis of variance for total dry weight (g) in plants after seven weeks of growth.

Source of Variation	df	SS	MS	F
A = CEC	2	18.6336	9.3168	17.86**
B = soil mixture	2	19.6253	9.8126	18.81**
C = Cd source	1	427.2939	427.2939	819.09**
AB	4	7.5589	1.8897	3.62**
AC	2	7.2003	3.6001	6.90**
BC	2	44.3036	22.1518	42.46**
ABC	4	8.9672	2.2418	4.30**
Error	54	28.1700	0.5217	
Total	71	561.75		

Significance levels for single degree of freedom comparisons

Comparison	Cd Source	
	Sludge	$CdCl_2$
CEC_L (linear) within Ava	n.s.	n.s.
CEC_Q (quadratic) within Ava	n.s.	n.s.
CEC_L within M/A (Maumee/Ava)	n.s.	*
CEC_Q within M/A	n.s.	n.s.
CEC_L within Maumee	n.s.	**
CEC_Q within Maumee	*	n.s.
[Ava vs. Maumee] within CEC_{Lo}	n.s.	n.s.
[M/A vs. mean (Ava + Maumee)] within CEC_{Lo}	*	*
[Ava vs. Maumee] within CEC_M	n.s.	**
[M/A vs. mean (Ava + Maumee)] within CEC_M	**	**
[Ava vs. Maumee] within CEC_H	n.s.	**
[M/A vs. mean (Ava + Maumee)] within CEC_H	**	n.s.

*, ** = significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = non-significant F-ratio.

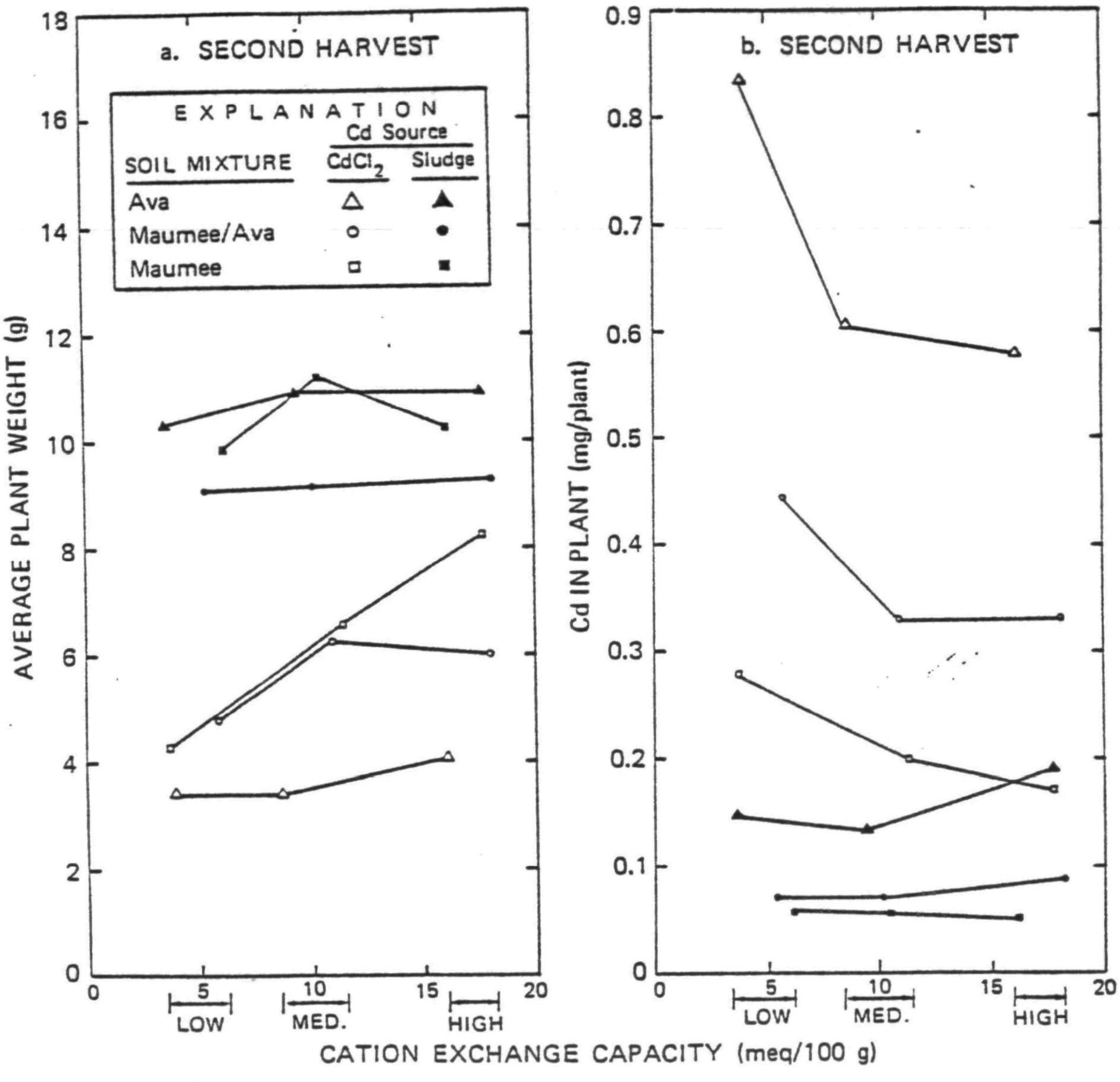

Figure 7. Mean weight (a) and amount of Cd accumulated (b) per plant for corn grown for 7 weeks on mixtures of soils combined to give 3 levels of CEC, containing 10 mg/kg of Cd derived from $CdCl_2$ or sewage sludge.

Table 43. Analysis of variance for mean total amounts (mg) of Cd accumulated per plant during seven weeks of growth.

Source of Variation	df	SS	MS	F
A = CEC	2	0.0771	0.0386	28.57**
B = soil mixture	2	0.9780	0.4890	362.20**
C = Cd source	1	1.8556	1.8556	1,374.42**
AB	4	0.0152	0.0038	2.81*
AC	2	0.0937	0.0468	34.70**
BC	2	0.3779	0.1890	139.96**
ABC	4	0.0213	0.0053	3.94**
Error	54	0.0729	0.0014	
Total	71	3.4917		

Significance levels for single degree of freedom comparisons

Comparison	Cd Source	
	Sludge	$CdCl_2$
CEC_L (linear) within Ava	n.s.	**
CEC_Q (quadratic) within Ava	n.s.	**
CEC_L within M/A (Maumee/Ava)	n.s.	**
CEC_Q within M/A	n.s.	*
CEC_L within Maumee	n.s.	**
CEC_Q within Maumee	n.s.	n.s.
[Ava vs. Maumee] within CEC_{Lo}	**	**
[M/A vs. mean (Ava + Maumee)] within CEC_{Lo}	n.s.	**
[Ava vs. Maumee] within CEC_M	**	**
[M/A vs. mean (Ava + Maumee)] within CEC_M	n.s.	**
[Ava vs. Maumee] within CEC_H	**	**
[M/A vs. mean (Ava + Maumee)] within CEC_H	n.s.	n.s.

*, ** = significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. = non-significant F-ratio.

by plants decreased from low to high CEC's by only 36%. Therefore, within a particular series, organic matter affected the amounts of Cd accumulated per plant very little, except for its contribution to additional soil CEC. Apparently, the difference in amounts of Cd accumulated by corn plants from different series of soil mixtures was controlled more strongly by some other factor than explained by differences in soil organic matter contents.

Cadmium contained in the digested sewage sludge must have been present in forms that inhibited its uptake to such an extent that soil difference in organic matter contents, CEC, pH, and particle size distribution were relatively unimportant. On the other hand, municipal sewage sludge may have supplied other substances that suppressed the availability of Cd or antagonized its uptake.

Conclusions

1. Generally, soil CEC inversely affected the uptake of Cd by corn and its growth when Cd was supplied as a soluble salt, but not when the Cd was supplied as a constituent of municipal sewage sludge. Thus, source of Cd was the most important factor affecting its uptake and impact on plant growth.

2. Where soil mixtures were amended with $CdCl_2$, tissue-Cd concentrations were higher and plant growth lower on soil mixtures that had low organic matter contents, at all equivalent levels of CEC. However, within a particular series of mixtures there was no evidence that soil organic matter decreased Cd uptake beyond its effect on soil CEC. Tissue-Cd concentrations and plant growth on sludge-amended soil mixtures were not significantly different regardless of soil CEC or its origin. Except for the series of soil mixtures with the lowest organic matter content (Ava B_1), sludge applied at a rate of 100 mt/ha did not significantly affect soil organic-C concentrations. Thus, the lack of a relationship between soil CEC and Cd concentrations in plants on these soil mixtures was not solely attributable to concomitant additions of sludge organic matter.

3. Total amounts of Cd accumulated per plant, as calculated from tissue-Cd concentrations and dry weight of harvested tissue, also varied inversely with soil CEC on $CdCl_2$-treated soil mixtures but not on those treated with sludge. However, total amounts of Cd accumulated per plant were significantly higher on sludge-treated Ava mixtures where CEC was due less to organic matter contents than other sources.

4. The results of this study indicate that the information obtained from studies using soluble salts of Cd cannot be extrapolated to predict potential hazards from sewage sludge, and perhaps other waste applied on land as a means of disposal. Further research is needed to determine why sludge-borne Cd was taken up to a lesser extent than that applied as a soluble salt. To explain why amounts of Cd accumulated by corn plants differed with respect to the dominant origin of soil CEC will require information not presently available.

UPTAKE OF METALS BY SPINACH GROWN ON SOIL AMENDED WITH SLUDGE AND $CdCl_2$

Introduction

Since many investigators have undertaken metal uptake studies with sludges artificially spiked with high levels of Cd salts, an experiment was designed to determine if the addition of a chemical source of cadmium ($CdCl_2$) to sludge produces the same uptake of metal as that of indigenous sludge-Cd. Spinach was chosen to evaluate Cd uptake because of its known high accumulation of the metal in its leaves.

Materials and Methods

A total of ten different sludges were used in the experiment; two each containing approximately 40, 140, 400, 600, and 1000 mg Cd/kg (dry weight). For the first 4 Cd levels, one sludge of each pair contained completely indigenous Cd; the other sludge contained a lower level of indigenous Cd and was spiked with $CdCl_2$ to raise its Cd content to that of the other member of the pair. Both sludges containing 1000 mg Cd/kg had additions of $CdCl_2$, but they differed in their initial indigenous content. Table 44 shows the Cd contents of the ten sludges as measured by atomic absorption spectrophotometry after their preparation.

Each of the ten sludges were admixed with appropriate amounts of Blount silt loam (Aeric ochraqualf, fine illitic, mesic, pH 7.4) to produce 9 kg of soil at each of the following loading rates: 10, 5, 2.5 and 1.25 kg Cd/ha.

The 10 kg Cd/ha rate corresponds to a soil level of 4.46 mg/kg Cd. An amount of liquid sludge was added to dry Blount silt loam to produce 18 kg of dry material at the 4.46 mg/kg rate for each of the ten sludge treatments. Each mixture was air dried on a sheet of Visqueen and stirred frequently. Portions of each were then mixed with untreated soil to produce the other rates by the following scheme: 1.25 kg Cd/ha (.558 mg/kg) = 1.12 kg mix + 7.88 kg soil; 2.5 kg Cd/ha (1.12 mg/kg) = 2.25 kg mix + 6.75 kg soil; 5.0 kg Cd/ha (2.23 mg/kg) = 4.5 kg mix + 4.5 kg soil; 10.0 kg Cd/ha (4.46 mg/kg) = 9 kg mix. Aliquots of soil at the four rates containing only $CdCl_2$ (applied by atomization) and one aliquot for control were also prepared.

After addition of N-P-K at the equivalent rate of 100 kg/ha, each aliquot of soil was thoroughly mixed in a twin shell soil blender and equally distributed to three eight-inch pots (3 kg soil/pot). Pots were arranged on three greenhouse benches in a completely randomized design. Approximately 10 seeds of Bloomsdale spinach were planted in each pot on 25 April 1980. After germination, the number of plants per pot was reduced to four.

Harvesting of plants began 24 June. Plants were cut when they had reached approximately commercial-sale size. Each sample was taken through three washings of distilled water, dried at 60°C, and ground in a Wiley mill to pass a 20-mesh screen. Plant samples (2g) were wet ashed in concentrated HNO_3 at 90°C followed by concentrated $HClO_4$ at 200°C, taken to dryness, and dissolved in 1 N HNO_3. Analyses for 13 chemical elements were done by atomic absorption spectrophotometry with appropriate background correction.

TABLE 44. TOTAL SOLIDS AND CADMIUM CONTENT OF THE TEN SLUDGES USED IN THE GREENHOUSE SPINACH EXPERIMENT.

Sludge Number	Date Collected	Source	% of Solids	Cd concentrations (mg/kg dry weight) original	after $CdCl_2$ addition	proposed
1	Dec. 1979	HPL[a]	10.2	41	41*	40
2	Dec. 1979	HPL	7.50	18	40	40
3	Dec. 1979	HPL	7.56	166	166*	140
4	Dec. 1979	HPL	7.57	18	159	140
5	July 1979	LL[b] #23	14.4	356	356*	400
6	July 1979	LL #29	8.7	218	398	400
7	July 1979	LL #20	17.7	541	541*	600
8	July 1979	LL #29	8.82	218	594	600
9	Dec. 1979	HPL	7.13	166	1020	1000
10	Dec. 1979	HPL	9.58	41	1120	1000

* No $CdCl_2$ added

[a]HPL = Hanover Park Lagoon

[b]LL = Lawndale Lagoon

Results

Data were analyzed by a two factor analysis of variance using three Cd sources and four loading rates for each of the five different levels of cadmium. Elemental levels in spinach tissue and statistical analyses are summarized in Tables 45-49. It was deemed inappropriate to use Cd level as a third factor, since within the sludge + $CdCl_2$ treatment, the varying Cd levels were achieved by different proportions of sludge and $CdCl_2$; analyses were therefore performed separately.

Discussion

The only elements that had consistently significant differences in uptake by spinach for both loading rates and Cd source were Cd and Zn. Significance for Zn uptake is certainly not surprising since appreciable amounts of it were added as components of sludge and these amounts, unlike Cd which was controlled, varied with the amount of sludge. Thus, Zn uptake generally decreased in the order of sludge > sludge + $CdCl_2$ > $CdCl_2$ because amounts of total soil Zn decreased.

Cd levels in spinach generally increased in the order of sludge < sludge + $CdCl_2$ < $CdCl_2$. This suggests that Cd is less available when applied as a constituent of sewage sludge than when applied as a soluble salt. However, the interaction of loading rate and Cd source was significant in all cases indicating complexities in the relationship which are not presently understood.

RESPONSES OF WHITE LEGHORN CHICKENS TO BIOLOGICALLY INCORPORATED CADMIUM

Introduction

Concentrations of several heavy and transition metals were increased in the foliage and grain of crops grown on soil amended with digested sewage sludge (Hinesly and Hansen, 1979). The most notable enhancements of metal concentrations in plant tissues were those of Zn and Cd. Except for Cd, most of the trace elements whose concentrations were increased in plant tissues by sludge applications are known to be essential elements for animals, and rations are frequently supplemented with mineral additives to provide them at levels required by modern breeds of animals. Cadmium has not yet been shown to be essential for animal health. However, it has been reported at low concentrations to be beneficial for the growth of rats (Schwarz and Spallholz, 1978). Short time studies where pheasants and swine were fed corn grain from soils with and without sewage sludge additions demonstrated that higher concentrations of grain-Cd caused increased Cd concentration in animal livers and kidneys without adversely affecting performance or health (Hinesly et al., 1976; Hansen et al., 1976; Hansen and Hinesly, 1979; Hinesly et al., 1979). It has been shown that Cd biologically incorporated into corn grain and soybeans is nearly as available for absorption by animals as that added to rations in the form of $CdCl_2$ (Buck et al., 1979). But, soluble Cd salts have generally been added to animal rations at much higher concentrations than were attainable from plant materials alone. Furthermore, single ion additions create a nutrient imbalance that generally can not be duplicated by using plant materials.

TABLE 45. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS (DRY WEIGHT) IN SPINACH GROWN ON BLOUNT SILT LOAM AMENDED WITH SEWAGE SLUDGE, SLUDGE PLUS $CdCl_2$ AND $CdCl_2$ AT RATES TO PROVIDE EQUIVALENT AMOUNTS OF TOTAL SOIL-CD. SLUDGE AND SLUDGE PLUS $CdCl_2$ CONTAINED 40 mg/kg (DRY WEIGHT) OF Cd.

Cd-Source	Cd-Loading Rate	K	Na	Ca	Mg	Fe	Mn	Zn	Cd	Cu	Ni	Cr	Pb	Al
		%				mg/kg								
Sludge	1.25	5.42	0.715	2.38	2.04	828.00	93.17	259.27	5.82	22.77	1.43	3.70	4.42	1203.33
	2.50	5.51	0.671	2.48	1.98	528.00	115.83	480.43	10.22	30.92	2.32	4.53	1.68	730.00
	5.0	5.72	0.850	2.61	1.82	591.67	255.87	520.57	15.13	40.78	1.67	4.95	2.04	837.33
	10.0	6.53	0.913	2.95	1.50	254.00	874.00	532.40	15.13	48.45	6.32	3.74	2.37	450.33
Sludge + $CdCl_2$	1.25	6.30	0.561	2.10	2.14	381.33	110.57	275.67	7.53	26.98	0.93	5.25	1.51	465.67
	2.5	5.00	0.692	2.49	2.20	839.33	127.97	423.70	13.95	36.73	1.67	5.39	1.97	1284.67
	5.0	5.87	0.782	2.91	1.93	444.33	367.20	512.30	20.99	42.80	2.50	11.03	2.37	586.00
	10.0	5.74	0.800	3.50	1.34	279.67	861.13	544.20	24.73	48.74	7.74	3.42	2.15	539.00
$CdCl_2$	1.25	6.86	0.574	1.89	1.98	739.33	115.17	116.90	4.97	17.58	1.29	2.93	1.82	1312.33
	2.5	6.75	0.544	1.66	1.93	564.67	103.63	115.57	7.87	25.48	2.09	2.28	1.55	962.00
	5.0	5.88	0.718	1.93	1.96	843.33	122.27	112.97	21.81	20.40	1.71	2.74	1.47	1248.33
	10.0	5.01	0.636	2.04	2.46	799.00	147.77	115.70	61.19	17.61	1.33	2.60	1.89	1298.67
F Ratio Significance Levels														
Loading Rate		n.s.	**	**	n.s.	n.s.	**	**	**	**	**	**	n.s.	n.s.
Cd Source		n.s.	**	**	*	n.s.	**	**	**	**	**	**	n.s	n.s.
Interaction		*	n.s.	n.s.	**	n.s.	**	**	**	**	**	**	n.s.	n.s.

*, **=Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

n.s.=No significant differences.

TABLE 46. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS (DRY WEIGHT) IN SPINACH GROWN ON BLOUNT SILT LOAM AMENDED WITH SEWAGE SLUDGE, SLUDGE PLUS $CdCl_2$, AND $CdCl_2$ AT RATES TO PROVIDE EQUIVALENT AMOUNTS OF TOTAL SOIL Cd. SLUDGE AND SLUDGE PLUS $CdCl_2$ CONTAINED 140 mg/kg (DRY WEIGHT) OF Cd.

Cd-Source	Cd-Loading Rate	K	Na	Ca	Mg	Fe	Mn	Zn	Cd	Cu	Ni	Cr	Pb	Al
	---kg/ha---	----------%----------				---------------------------mg/kg---------------------------								
Sludge	1.25	6.42	0.644	2.03	1.96	554.33	97.20	144.77	9.05	20.99	1.73	3.75	2.05	892.67
	2.5	7.04	0.452	2.00	1.86	723.67	98.77	171.70	11.92	21.33	1.57	3.96	2.12	1150.00
	5.0	7.10	0.781	2.21	1.82	456.67	92.80	199.17	14.00	19.95	1.30	3.76	1.70	669.00
	10.0	6.47	0.924	2.45	1.98	636.33	127.23	336.80	28.54	31.16	2.23	4.46	2.30	1126.00
Sludge + $CdCl_2$	1.25	6.78	0.547	1.77	2.10	461.00	83.07	166.97	12.26	31.22	1.48	4.54	1.74	681.00
	2.5	5.73	0.766	2.59	1.86	1575.33	106.80	155.17	13.73	24.29	3.01	4.31	3.88	2132.33
	5.0	5.47	0.602	3.00	2.02	995 33	120.43	277.57	33.39	33.18	2.52	3.29	3.18	1226.00
	10.0	5.95	0.742	2.60	2.08	470.67	62.97	361.23	31.00	35.71	2.53	3.54	2.42	595.00
$CdCl_2$	1.25	6.86	0.574	1.89	1.98	739.33	115.17	116.90	4.97	17.58	1.29	2.93	1.82	1312.33
	2.5	6.75	0.544	1.66	1.93	564.67	103.63	115.57	7.87	25.48	2.09	2.28	1.55	962.00
	5.0	5.88	0.718	1.93	1.96	843.33	122.27	112.97	21.81	20.40	1.71	2.74	1.47	1248.33
	10.0	5.01	0.636	2.04	2.46	799.00	147.77	115.70	61.19	17.61	1.33	2.60	1.89	1298.67
F Ratio Significance Levels														
Loading Rate		n.s.	*	**	n.s.	n.s.	n.s.	**	**	n.s.	*	n.s.	n.s.	n.s.
Cd Source		*	n.s.	**	n.s.	n.s.	**	**	n.s.	**	**	**	*	n.s.
Interaction		n.s.	*	*	n.s.	n.s.	**	**	**	n.s.	n.s.	n.s.	n.s.	n.s.

*, **=Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

n.s.=No significant differences.

TABLE 47. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS (DRY WEIGHT) IN SPINACH GROWN ON BLOUNT SILT LOAM AMENDED WITH SEWAGE SLUDGE, SLUDGE PLUS $CdCl_2$ AND $CdCl_2$ AT RATES TO PROVIDE EQUIVALENT AMOUNTS OF TOTAL SOIL-Cd. SLUDGE AND SLUDGE PLUS $CdCl_2$ CONTAINED 400 mg/kg (DRY WEIGHT) OF Cd.

Cd-Source	Cd-Loading Rate	K	Na	Ca	Mg	Fe	Mn	Zn	Cd	Cu	Ni	Cr	Pb	Al
	---kg/ha---	----------%----------				----------mg/kg----------								
Sludge	1.25	7.09	0.488	1.98	2.10	723.33	128.87	177.27	6.45	14.91	2.55	5.02	2.60	907.00
	2.5	5.76	0.784	2.47	2.14	751.00	134.70	205.33	8.17	18.63	3.29	6.17	2.21	932.00
	5.0	6.25	0.553	2.46	2.06	787.67	145.93	324.70	14.01	18.46	2.67	5.17	1.50	1020.00
	10.0	6.34	0.716	1.99	2.26	484.67	104.07	469.60	16.22	22.31	2.20	7.54	1.15	647.33
Sludge + $CdCl_2$	1.25	6.56	0.559	1.94	1.85	956.33	145.33	160.00	16.51	8.14	1.98	5.31	1.79	1362.33
	2.5	5.69	0.533	2.14	2.47	853.67	166.97	227.10	23.43	23.81	2.45	5.66	3.35	1214.00
	5.0	6.70	0.527	1.92	2.38	897 33	171.20	242.97	28.60	23.29	2.42	4.14	2.30	1349.00
	10.0	6.12	0.562	2.67	1.87	795.67	173.87	408.57	47.42	32.72	3.11	5.22	2.63	1089.33
$CdCl_2$	1.25	6.86	0.574	1.89	1.98	739.33	115.17	116.90	4.97	17.58	1.29	2.93	1.82	1312.33
	2.5	6.75	0.544	1.66	1.93	564.67	103.63	115.57	7.87	25.48	2.09	2.28	1.55	962.00
	5.0	5.88	0.718	1.93	1.96	843.33	122.27	112.97	21.81	20.40	1.71	2.74	1.47	1248.33
	10.0	5.01	0.636	2.04	2.46	799.00	147.77	115.70	61.19	17.61	1.33	2.60	1.89	1298.67
F Ratio Significance Levels														
Loading Rate		n.s.	n.s	n.s.	n.s.	n.s.	n.s.	**	**	*	n.s.	n.s.	n.s.	n.s.
Cd Source		n.s.	n.s.	**	n.s.	n.s.	**	**	**	n.s.	**	**	n.s	n.s.
Interaction		n.s.	n.s.	*	n.s.	n.s.	n.s.	**	**	n.s.	n.s.	n.s.	n.s.	n.s.

*, **=Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

n.s.=No significant differences.

TABLE 48. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS (DRY WEIGHT) IN SPINACH GROWN ON BLOUNT SILT LOAM AMENDED WITH SEWAGE SLUDGE, SLUDGE PLUS $CdCl_2$ AND $CdCl_2$ AT RATES TO PROVIDE EQUIVALENT AMOUNTS OF TOTAL SOIL Cd. SLUDGE AND SLUDGE PLUS $CdCl_2$ CONTAINED 600 mg/kg (DRY WEIGHT) OF Cd.

Cd-Source	Cd-Loading Rate	K	Na	Ca	Mg	Fe	Mn	Zn	Cd	Cu	Ni	Cr	Pb	Al
		%				mg/kg								
Sludge	1.25	6.65	0.526	2.20	1.84	710.00	113.20	134.37	6.42	15.62	1.70	5.97	1.93	1029.00
	2.5	7.29	0.658	2.16	1.88	364.67	133.33	206.77	9.14	17.61	1.46	6.02	1.93	485.00
	5.0	5.80	0.554	2.55	2.14	1427.67	164.90	243.03	14.00	15.56	1.95	5.33	3.83	2227.67
	10.0	5.84	0.737	2.38	2.29	638.67	140.20	358.97	20.57	23.89	1.44	5.65	1.83	905.33
Sludge + $CdCl_2$	1.25	6.15	0.709	1.97	1.60	538.00	106.50	121.57	7.25	22.79	1.25	4.46	2.36	821.33
	2.5	6.70	0.584	2.02	2.01	802.67	127.17	146.47	11.70	18.12	1.11	4.19	2.24	1115.67
	5.0	6.37	0.488	2.09	2.08	1347.00	140.43	206.47	27.26	22.71	1.36	3.27	7.03	1861.67
	10.0	5.84	0.571	2.32	2.07	759.00	99.03	245.27	32.83	22.13	1.32	2.98	2.11	1030.67
$CdCl_2$	1.25	6.86	0.574	1.89	1.98	739.33	115.17	116.90	4.97	17.58	1.29	2.93	1.82	1312.33
	2.5	6.75	0.544	1.66	1.93	564.67	103.63	115.57	7.87	25.48	2.09	2.28	1.55	962.00
	5.0	5.88	0.718	1.93	1.96	843.33	122.27	112.97	21.81	20.40	1.71	2.74	1.47	1248.33
	10.0	5.01	0.636	2.04	2.46	799.00	147.77	115.70	61.19	17.61	1.33	2.60	1.89	1298.67
F Ratio Significance Levels														
Loading Rate		*	n.s.	n.s.	**	n.s.	n.s.	**	**	n.s.	n.s.	n.s.	*	n.s.
Cd Source		n.s.	n.s.	*	n.s.	n.s.	n.s.	**	**	n.s.	n.s.	**	n.s	n.s.
Interaction		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	**	n.s.	n.s.	n.s.	n.s.	n.s.

*, **=Significantly different at P≤0.05 and P≤0.01, respectively.

n.s.=No significant differences.

TABLE 49. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS (DRY WEIGHT) IN SPINACH GROWN ON BLOUNT SILT LOAM AMENDED WITH TWO DIFFERENT SLUDGE PLUS $CdCl_2$ MIXTURES OR $CdCl_2$ AT RATES TO PROVIDE EQUIVALENT AMOUNTS OF TOTAL SOIL-Cd. BOTH SLUDGES CONTAINED 1000 mg/kg (DRY WEIGHT) OF Cd. SLUDGE I WAS COMPOSED OF SLUDGE WITH 40 mg Cd/kg PLUS $CdCl_2$; SLUDGE II WAS COMPOSED OF SLUDGE WITH 140 mg Cd/kg PLUS $CdCl_2$.

Cd-Source	Cd-Loading Rate	K	Na	Ca	Mg	Fe	Mn	Zn	Cd	Cu	Ni	Cr	Pb	Al
	---kg/ha---	----------%----------				----------mg/kg----------								
Sludge I	1.25	7.26	0.533	1.85	1.76	492.33	70.13	102.63	9.83	16.01	1.74	2.78	1.88	705.33
	2.5	5.93	0.506	2.06	1.92	1311.67	122.97	98.20	11.97	15.80	1.73	3.94	5.44	1854.33
	5.0	7.11	0.561	1.88	1.99	452.67	88.93	1131.80	18.81	18.75	1.52	3.17	1.49	693.00
	10.0	6.41	0.570	2.09	2.21	1146.00	118.60	169.60	11.76	18.31	1.87	4.08	2.38	1756.00
Sludge II	1.25	6.67	0.411	7.61	2.13	503.00	131.00	119.53	2.25	19.17	1.43	2.17	8.98	825.00
	2.5	6.34	0.524	1.93	1.92	819.33	116.40	121.83	4.93	17.67	1.23	3.18	3.31	1206.00
	5.0	5.81	0.682	1.82	1.97	820.00	128.33	148.73	13.79	20.00	1.20	2.89	2.47	1337.33
	10.0	6.72	0.546	2.03	2.16	460.33	115.33	169.03	12.12	19.17	1.41	2.28	1.51	710.33
$CdCl_2$	1.25	6.86	0.574	1.89	1.98	739.33	115.17	116.90	4.97	17.58	1.29	2.93	1.82	1312.33
	2.5	6.75	0.544	1.66	1.93	564.67	103.63	115.57	7.87	25.48	2.09	2.28	1.55	962.00
	5.0	5.88	0.718	1.93	1.96	843.33	122.27	112.97	21.81	20.40	1.71	2.74	1.47	1248.33
	10.0	5.01	0.636	2.04	2.46	799.00	147.77	115.70	61.19	17.61	1.33	2.60	1.89	1298.67
F Ratio Significance Levels														
Loading Rate		n.s.	n.s.	n.s.	**	n.s.	n.s.	**	**	n.s.	n.s.	n.s.	n.s.	n.s.
Cd Source		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	**	n.s.	n.s.	**	n.s	n.s.
Interaction		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	**	n.s.	n.s.	n.s.	n.s.	n.s.

*, **=Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

n.s.=No significant differences.

The main objectives of the study reported here were to produce corn (Zea mays L.) grain and soybean (Glycine max L.) with the highest concentration of Cd obtainable from healthy plants for use in formulating rations for chicks and throughout their productive life as layers. Laying hens consume higher amounts per body weight of food materials than other animals and would therefore be more likely to exhibit adverse health and performance effects from the absorption and accumulation of Cd than other animals.

Methods and Materials

Single crosses of corn were selected on the basis of their capacities to accumulate high (No17 x Fr14A) and intermediate (R802A x R806) concentrations of Cd in grain from the sewage sludge-amended strip-mined spoil where they were planted. Sufficient corn grain having Cd concentrations of 0.71 and 0.35 mg/kg was obtained from the strip-mined area to provide materials for formulating the high and intermediate Cd levels for the feeding study. Commercial corn grain containing less than 0.06 mg Cd/kg of grain was used in low-Cd rations. After processing, the meal from soybeans (Woodworth and Harosoy 63) grown on sludge-amended strip-mined spoil contained 2.38 mg/kg of Cd and was used to formulate the high-Cd rations. The intermediate-Cd rations were formulated using a half and half mixture of the high-Cd soybean meal and a commercial soybean meal containing less than 0.06 mg Cd/kg. The commercial meal was used in the low-Cd rations. Mineral and vitamin supplements were added to rations in amounts and from sources that are generally used in commercial poultry operations. The experimental diets are shown in Table 50. Mean concentrations of Zn, Cd, Cu, Mn, Fe, Pb, Cr, Ni, Se, Mg, Ca, and P in low-, medium-, and high-Cd diets (LCd, MCd, and HCd) are presented in Table 51.

Three hundred commercial hybrid pullet chicks (Hyline W36) were brooded in lots of 25 each in a Petersime Brooder Battery. At six weeks of age they were transferred by lots to growing batteries. From 20 to 80 weeks of age they were housed two birds per cage in 25.4 x 45.7 cm laying cages. The HCd, MCd and LCd diets (Table 51) were each fed to four lots of birds ad libitum. Starter, developer, and layer diets were fed from 0-8, 8-20, and 20-80 weeks of age, respectively. Distilled or deionized water was provided ad libitum in stainless steel or plastic waterers throughout the assay.

The birds were housed in environmentally controlled quarters maintained at 16-27°C with heaters and air conditioners as needed. A standard step down-step up lighting schedule was provided following the first five days during which lighting was continuous.

Feed intake and body weights were determined at biweekly intervals from 0-8 weeks of age and by 4-week periods thereafter. Egg production was measured daily and egg weight and specific gravity were determined from a 3-day collection of eggs taken at the end of each 4-week period starting during the 28th week.

The experiment was initiated with 4 replications of birds on each of the LCd, MCd, and HCd diets. Samples of brids were terminated at 8, 20, 50, 72, and 80 weeks by cervical dislocation and decapitation. At 8 and 50 weeks, 4

Table 50. Experimental diet.

Ingredient[1]	LCd[4] Start[2]	LCd[4] Dev	LCd[4] Layer[3]	MCd[4] Starter[2]	MCd[4] Dev	MCd[4] Layer[3]	HCd[4] Start[2]	HCd[4] Dev	HCd[4] Layer[3]
High cadmium corn (12.1% P)	-	-	-	-	-	-	71.63	86.63	69.10
Medium cadmium corn (10.6% P)	-	-	-	56.59	67.58	53.70	-	-	-
Low cadmium corn (9.6% P)	69.90	82.60	64.50	13.27	15.85	12.60	-	-	-
High cadmium soybean meal (46.4% P)	-	-	-	11.62	6.46	11.60	21.47	9.72	20.40
Low cadmium soybean meal (51.4% P)	23.20	13.75	25.00	11.62	6.46	11.60	-	-	-
Corn gluten meal (60% P)	2.00	-	-	2.00	-	-	2.00	-	-
Alfalfa meal (17% P)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DL-methionine	.05	-	-	.05	-	-	.05	-	-
Dicalcium phosphate	2.20	1.00	1.25	2.20	1.00	1.25	2.20	1.00	1.25
Ground limestone	1.00	1.00	7.50	1.00	1.00	7.50	1.00	1.00	7.50
Iodized salt	.40	.40	.40	.40	.40	.40	.40	.40	.40
Manganese sulfate (27% Mn)	.05	.05	.05	.05	.05	.05	.05	.05	.05
Choline chloride (50%)	.05	.05	.05	.05	.05	.05	.05	.05	.05
Vitamin mix #[5]	.10	.10	-	.10	.10	-	.10	.10	-
Layer vitamin mix	-	-	.25	-	-	.25	-	-	.25
Tylosin	.05	.05	-	.05	.05	-	.05	.05	-

[1] High, medium, low cadmium corn contained .71, .35, and <.06 mg Cd/kg. High and low cadmium soybean meal contained 2.38 and <.06 mg Cd/kg. Dicalcium phosphate and limestone contained 5.55 and 0.55 mg Cd/kg, respectively.

[2] LCd, MCd, and HCd starter diets contained .22, .76, and 1.22 mg Cd/kg.

[3] LCd, MCd, and HCd layer diets contained .10, .57, and .97 mg Cd/kg.

[4] Starter, developer and layer diets formulated to contain low (LCd), medium (MCd), and high (HCd) in cadmium.

[5] Provided per kg of starter and developer diet: vitamin A 2,000 I.U.; D_3 1,000 ICU; K 1 mg; niacin 27 mg; calcium pantathonate 11 mg; B_{12} 9 mcg; biotin 100 mcg; riboflavin 3.6 mg. Provided per kg of layer diet: vitamin A 4400 I.U.; D_3 1,000 ICU; vitamin K 1.1 mg; niacin 22 mg; calcium pantothenate 11 mg; B_{12} 12.5 mcg; E 2.2 mg; riboflavin 4.4 mg; chlortetracycline 20 mg/ton.

Table 51. Mean concentrations of selected elements in feed samples of low-, medium-, and high-Cd diets formulated from corn and soybeans grown on sludge-amended soil.

Cd Diet	Chemical Element: Zn	Cd	Cu	Mn	Fe	Pb	Cr	Ni	Se	Mg	Ca	P
	mg/kg									%		
Low: $\bar{x}$	29.4	0.095	5.44	175	393	<0.625	2.23	3.38	0.017	0.181	2.54	0.857
s.d.	3.9	0.047	1.03	32	99	–	0.67	0.52	0.01	0.016	1.25	0.454
Medium: $\bar{x}$	44.4	0.567	5.88	170	398	<0.625	2.17	4.53	0.025	0.191	2.44	0.811
s.d.	5.7	0.107	1.49	23	113	–	0.36	0.65	0.016	0.029	1.47	0.171
High: $\bar{x}$	48.5	0.966	6.07	170	380	<0.625	2.21	4.91	0.033	0.155	2.66	0.966
s.d.	8.9	0.135	1.96	32	83	–	0.80	0.88	0.012	0.031	1.36	0.263

birds were sampled from each of the 4 replications and tissues collected for residue and chemical analyses and pathological examination were pooled within each replication. Sampling procedures at 20 weeks were the same, except only 3 birds per replication were sacrificed. At the end of 52 weeks, 2 of the 4 replications of hens fed LCd diets were switched to HCd diets and vice versa. This created two new treatments designated LCd to HCd and HCd to LCd. At the 72 and 80 week sampling periods 5 birds from each of the remaining 2 replications per treatment were randomly selected and tissues from each bird were analyzed separately.

Small hematologic blood samples were collected from wing veins and larger samples by cardiac puncture for serum clinical chemistry analyses. Measurements of potential manifestation of toxicosis (clinical chemistry, hematology, and histopathology) were conducted using standard techniques. Dissection techniques for collecting samples of heart, lung, liver, pancreas, spleen, kidney, breast muscle, leg muscle, femur bone, brain, crop, proventriculus, gizzard, and duodenum were previously described in detail (Hinesly et al., 1976), along with method preparation and analysis for various chemical constituents. All tissues and primary wing feathers were analyzed for Zn, Cd, Cu, Mn, Fe, and Pb. The shell, white, and yolk of eggs were analyzed for Cd. Feathers were washed in double-distilled water, dried (60°C), ground in a Wiley mill, and digested in concentrated HNO_3 (90°C) until fuming ceased. Then they were digested with 30% H_2O_2, taken to dryness, and dissolved in 0.5 N HNO_3 for analysis by atomic absorption spectrophotometry. Eggs were washed in distilled water before boiling in plastic cooking bags, after which shells, white, and yolk were separated, dried (60°C) and ground in a Wiley mill. Shells were prepared for analyses by the procedure used for feathers. Methods used to analyze other chicken tissues were employed for the analysis of egg whites and yolks.

Results and Discussion

General Health and Performance--

In the absence of selecting corn hybrids and soybean cultivars for inherited capacities to take up high amounts of Cd and growing these on soils treated with sewage sludges at rates which supply nitrogen and/or phosphorus in excess of crop requirements, the high-Cd diet (Table 51) represents the maximum dietary insult that poultry will encounter from biologically incorporated Cd. But there is no indication that enhanced concentrations of Cd adversely affected consumption of feed (Table 52) and cumulative gains in body weights of chicks, broilers, and hens (Table 53). Both feed intake and gains remained fairly constant after 24 weeks, regardless of dietary Cd concentrations. The ratio of feed consumption to body weight gain was not significantly affected by Cd treatment. The rate of egg laying, presented in Table 54, showed no significant differences associated with concentrations of Cd in diets. Decreases in egg production with age were about the same for the three Cd treatments. The rate of mortality, normally about 1% each 4-week period, was well below expectations for all diets (Table 55). Different concentrations of Cd in diets had no effect on egg weight, shell quality, and concentrations of Cd in egg parts. The data presented in Table 56 shows that egg whites and yolks generally contained Cd concentrations that were below the detectable limits of 0.062 mg/kg. Egg shells contained measurable amounts of Cd and these amounts increased as age of hens increased and rate of lay decreased, but shell-Cd concentrations were not affected by Cd levels in diets.

Concentrations of Selected Chemical Elements--

Concentrations of Zn, Cd, Cu, Mn, Fe, and Pb in various tissues of 8-week old chicks are shown in Table 57. No increased concentration of these metals in breast and leg muscle could be attributed to higher level in diets. But, in gizzard, kidney, and liver tissues, Cd concentrations reflected levels of the metal in diets. Data presented in Table 58 shows that concentrations of Ca, Na, Mg, K, and P in the several tissues from 8-week old chicks were not significantly affected by dietary-Cd differences. The barely significant differences in Ca concentrations in breast muscle and kidney tissues were evidently artifacts as judged by later data.

Zinc, Cd, Cu, Mn, Fe, and Pb concentrations in tissues of 20-week old chickens are presented in Table 59. Cadmium concentrations in gizzard, kidney, and liver tissues were significantly increased by increased concentrations in diets. Furthermore, Cd concentrations in these three tissues from 20-week old birds were significantly higher than those from 8-week old chicks at all dietary Cd levels. Other significant differences in metal concentrations in tissues show that these were not related to differences in diets and in light of data from similar tissues collected at earlier and later dates, apparently were artifacts. This is also true for concentrations of Ca, Na, Mg, K, and P in various tissues from 20-week old birds (Table 60).

In addition to those analyzed at the end of 8 and 20 weeks, several other tissues collected at 50 and 80 weeks were analyzed for heavy metal concentrations and are exhibited in Tables 61 and 64. At 50 weeks, the concentrations in brain and primary wing feathers appeared to decrease as Cd concentrations in diets increased, but this was not borne out by samples collected at 80 weeks. Results from analyses of 50 week samples of breast muscle, leg muscle, and femur bone, showed only Cd concentrations to be different in leg muscle, but unrelated to concentrations of the element in diets. Concentration of Cd in crop, proventriculus, gizzard, gizzard lining, duodenum, liver, pancreas, kidney, and lung were markedly increased by higher Cd concentrations in diets. The two higher dietary-Cd concentrations may have caused small, but significant, increased concentrations of Cd in spleen. Cadmium concentrations in 50 week heart tissue were not affected by dietary-Cd levels. Concentrations of Cd in 50 week samples of gizzard, kidney, and liver were significantly higher than they were in 20 week samples of the same tissues at all levels of dietary-Cd. Concentrations of alkali and alkaline earth metals and P in 50 week tissue samples were either not significantly changed or were not related to Cd concentrations in diets (Table 62).

Tissue samples collected at 72 weeks to facilitate toxicological measurements showed increased concentrations of Cd in gizzard, gizzard lining, kidney, and liver that corresponded with Cd levels in diets (Table 63). Whether or not there were differences in Cd concentrations in breast muscle and leg muscle is debatable because statistical analysis was performed by using one-half of the lowest detectable concentration in each case. Concentrations of Cd at 72 weeks were markedly increased over those at 50 weeks only in kidneys.

Table 52. Grams of feed consumed per bird per day (g/b/d) during 2- or 4-week interval periods of the 80-week study.

Period (weeks)	Diet g/b/d	g/b/d	g/b/d
0-2	11.85 ± .10	11.50 ± .14	11.38 ± .13
2-4	24.45 ± .13	24.20 ± .30	25.40 ± .22
4-6	36.75 ± .32	36.20 ± .24	36.80 ± .24
6-8	49.53 ± .47	50.15 ± .28	50.68 ± .66
8-12	52.63 ± .23	53.03 ± .58	56.10 ± .39
12-16	47.08 ± .86	47.63 ± .26	49.60 ± .45
16-20	57.45 ± .83	55.55 ± .65	55.78 ± .26
20-24	66.28 ± 1.46	64.35 ± 1.65	64.95 ± 1.49
24-28	90.43 ± 1.10	89.30 ± 1.70	87.95 ± 1.20
28-32	91.67 ± .89	91.75 ± 1.07	94.83 ± 3.04
32-36	104.73 ± 3.73	97.68 ± 3.22	92.03 ± 2.12
36-40	97.32 ± 1.53	96.28 ± 3.91	95.90 ± 1.66
40-44	99.10 ± 1.98	96.85 ± 5.56	97.30 ± 4.97
44-48	95.95 ± 1.43	93.75 ± 2.42	94.05 ± 2.67
48-52	L-L[1/] 100.35 ± .85	96.65 ± 1.99	H-H[1/] 92.60 ± 1.80
	L-H 97.55 ± 1.55	-	H-L 98.10 ± .90
52-56	L-L 99.95 ± 1.05	93.90 ± 2.53	H-H 90.45 ± 6.16
	L-H 91.00 ± 7.12	-	H-L 97.45 ± 3.16
56-60	L-L 99.95 ± 1.05	95.17 ± 4.49	H-H 90.35 ± 4.96
	L-H 87.90 ± 4.51	-	H-L 99.40 ± .68
60-64	L-L 95.80 ± 1.50	97.55 ± 3.42	H-H 87.85 ± 9.40
	L-H 87.05 ± 1.35	-	H-L 103.05 ± 1.65
64-68	L-L 94.85 ± 2.46	90.73 ± 4.00	H-H 89.20 ± 2.71
	L-H 82.20 ± 2.91	-	H-L 98.05 ± .75
68-72	L-L 81.65 ± 3.06	86.55 ± 2.73	H-H 78.95 ± 3.26
	L-H 84.05 ± 6.77	-	H-L 93.80 ± .20
72-80	L-L 87.70 ± 7.32	86.90 ± 3.23	H-H 83.95 ± 2.0
	L-H 90.45 ± 1.55	-	H-L 86.40 ± 8.5

[1/] Four replications to 52 weeks. At 52 weeks 2 LCd replications were changed to HCd (L-H) and 2 continued on LCd (L-L). Reciprocal changes were also made for HCd treatment. Birds on MCd were not changed.

Table 53. Cumulative gains in body weight of survivors for indicated periods.

Period 0-80 weeks	Diet LCd		MCd	HCd	
		gm ± SEM	gm ± SEM		gm ± SEM
2		70.50 ± 1.19	68.25 ± 1.11		64.75 ± .75
4		211.50 ± 2.10	209.00 ± 1.29		201.50 ± 3.50
6		378.00 ± 3.49	371.75 ± 2.78		360.00 ± 3.87
8		570.25 ± 3.07	566.50 ± 4.09		560.50 ± 2.40
12		879.00 ± 1.22	872.00 ± 7.38		885.25 ± 3.20
16		1056.25 ± 9.34	1064.75 ± 9.56		1088.25 ± 6.66
20		1298.00 ± 10.21	1287.00 ± 10.35		1304.25 ± 12.10
24		1364.50 ± 4.66	1345.50 ± 7.38		1342.25 ± 14.53
28		1385.50 ± 13.57	1360.25 ± 17.38		1342.50 ± 21.80
32		1400.00 ± 16.56	1360.00 ± 16.90		1339.75 ± 22.95
36		1430.25 ± 7.11	1376.25 ± 26.57		1361.50 ± 22.80
40		1438.50 ± 13.22	1379.75 ± 33.11		1367.00 ± 25.93
44		1442.00 ± 14.73	1392.25 ± 24.36		1364.75 ± 27.89
48		1456.75 ± 11.23	1411.00 ± 25.66		1391.25 ± 28.76
52	L-L[1/]	1471.50 ± 14.50	1407.00 ± 25.46	H-H[1/]	1360.50 ± 25.50
	L-H	1469.00 ± 6.00	-	H-L	1445.00 ± 49.00
56	L-L	1465.50 ± 10.50	1411.50 ± 23.10	H-H	1340.00 ± 46.00
	L-H	1439.00 ± 17.00	-	H-L	1439.50 ± 18.50
60	L-L	1470.00 ± 9.00	1424.00 ± 27.68	H-H	1363.50 ± 30.50
	L-H	1432.00 ± 9.00	-	H-L	1451.00 ± 16.00
64	L-L	1479.50 ± 8.50	1438.50 ± 23.15	H-H	1363.50 ± 30.50
	L-H	1446.50 ± 9.50	-	H-L	1500.00 ± 23.00
68	L-L	1489.50 ± 12.50	1428.00 ± 11.10	H-H	1355.50 ± 30.50
	L-H	1411.00 ± 14.00	-	H-L	1478.50 ± 20.50
72	L-L	1431.00 ± 4.00	1400.75 ± 15.40	H-H	1335.00 ± 38.00
	L-H	1410.50 ± 29.50	-	H-L	1462.00 ± 20.00
80	L-L	1416.00 ± 32.00	1438.00 ± 40.06	H-H	1393.50 ± 37.50
	L-H	1445.50 ± 12.50	-	H-L	1455.50 ± 3.50

1/ Four replications to 52 weeks. At 52 weeks 2 LCd replications were changed to HCd (L-H) and 2 continued on LCd (L-L). Reciprocal changes were also made for HCd treatment. Birds on MCd were not changed.

Table 54. Percent of surviving hens laying an egg per day (HD%) from 20-80 weeks by 4-week intervals.

Period (weeks)	LCd HD% ± SEM	MCd HD% ± SEM	HCd HD% ± SEM
20-24	40.70 ± 2.99	44.53 ± 6.52	36.35 ± 4.47
24-28	84.08 ± 2.38	80.25 ± 1.88	86.43 ± 3.13
28-32	85.03 ± 1.73	84.88 ± 2.39	88.78 ± 1.25
32-36	84.35 ± 1.00	84.15 ± 1.35	87.43 ± 1.25
36-40	75.70 ± 2.67	79.05 ± 3.15	80.03 ± 2.17
40-44	69.85 ± 3.21	72.08 ± 5.00	77.38 ± 1.73
44-48	64.98 ± .92	68.00 ± 5.66	70.53 ± 3.51
48-52	L-L[1/] 64.85 ± 4.66	65.70 ± 2.97	H-H[1/] 70.35 ± 2.46
	L-H 59.80 ± 5.72	-	H-L 62.15 ± 3.56
52-56	L-L 67.55 ± 3.25	65.63 ± 1.78	H-H 59.50 ± 11.60
	L-H 56.55 ± 13.45	-	H-L 66.80 ± 5.10
56-60	L-L 57.45 ± 6.45	63.20 ± 1.37	H-H 57.90 ± 12.90
	L-H 64.50 ± 2.70	-	H-L 66.80 ± 7.10
60-64	L-L 54.35 ± 1.85	4.15 ± .58	H-H 62.40 ± 13.20
	L-H 49.45 ± .95	-	H-L 69.10 ± .90
64-68	L-L 57.05 ± 5.25	61.78 ± 3.25	H-H 58.05 ± 5.65
	L-H 48.60 ± .40	-	H-L 63.90 ± 4.50
68-72	L-L 46.55 ± 1.85	56.28 ± 2.04	H-H 59.35 ± 5.45
	L-H 47.90 ± 4.72	-	H-L 60.15 ± 4.85
72-76	L-L 35.75 ± .65	43.42 ± 4.58	H-H 35.55 ± 2.75
	L-H 43.90 ± 2.50	-	H-L 43.75 ± .85
76-80	L-L 36.40 ± 2.00	46.23 ± 5.82	H-H 45.00 ± 4.31
	L-H 45.10 ± 7.60	-	H-L 42.00 ± 10.00

[1/] Four replications to 52 weeks. At 52 weeks 2 LCd replications were changed to HCd (L-H) and 2 continued on LCd (L-L). Reciprocal changes were also made for HCd treatment. Birds on MCd were not changed.

Table 55. Disposition of birds, 0-80 weeks of age.

Replicate	Fate[1/]	Diet LCd	MCd	HCd
1	Started	26	26	26
	Died	0	4	1
	To Analysis	18	16	17
2	Started	25	26	25
	Died	2	1	2
	To Analysis	17	13	17
3	Started	25	25	25
	Died	2	3	1
	To Analysis	18	14	18
4	Started	25	25	25
	Died	2	2	2
	To Analysis	18	15	18
1-4	Started	101	102	101
	Dead	6	10	6
	To Analysis	71	58	70
	Live, 80 weeks	24	34	25

[1/] Birds sacrificed at 8, 20, 50, and 72 weeks for tissue analysis.

Table 56. Mean Cd concentrations in egg constituents sampled at various intervals during a 54-week period commencing when egg laying began.

Number of Weeks After Laying Began	Cd Treatment	White	Yolk	Shell
6	low	<0.062	<0.062	0.114
	medium	<0.062	<0.062	0.149
	high	<0.062	<0.062	0.148
	F-test	n.s.	n.s.	n.s.
15	low	<0.062	0.068	0.068
	medium	<0.062	<0.062	0.071
	high	<0.062	0.111	0.090
	F-test	n.s.	n.s.	n.s.
24	low	<0.062	<0.062	0.101
	medium	<0.062	<0.062	0.124
	high	<0.062	<0.062	0.088
	F-test	n.s.	n.s.	n.s.
32	low	<0.062	<0.062	0.352
	medium	<0.062	<0.062	0.365
	high	<0.062	<0.062	0.294
	F-test	n.s.	n.s.	n.s.
41	low	0.317	<0.062	0.456
	medium	0.144	<0.062	0.320
	high	0.125	<0.062	0.340
	F-test	n.s.	n.s.	n.s.
54	low	<0.062	<0.062	0.303
	medium	<0.062	<0.062	0.325
	high	<0.062	<0.062	0.347
	F-test	n.s.	n.s.	n.s.

Table 57. Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. Samples taken 8 weeks after hatching.

Diet	Zn	Cd	Cu	Mn	Fe	Pb
	Chemical Element					
	mg/kg fat-free dry weight					
			Breast Muscle			
Low	19.7	<0.062	1.97	0.198	6.25	<0.625
Medium	20.2	<0.062	1.66	0.294	8.80	0.640
High	20.7	<0.062	1.61	0.227	8.48	1.02
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
			Gizzard			
Low	105	0.716	8.63	9.82	103	0.692
Medium	111	3.19	8.06	10.3	94.0	<0.625
High	106	4.54	7.80	9.20	91.5	0.738
LSD	n.s.	1.23**	0.55**	n.s.	7.6*	n.s.
			Kidney			
Low	92.4	0.304	11.2	13.0	236	<0.625
Medium	107	1.76	12.4	13.1	229	0.970
High	110	3.21	12.8	13.4	241	<0.625
LSD	8.6**	0.813**	n.s.	n.s.	n.s.	n.s.
			Leg Muscle			
Low	81.3	0.078	5.03	0.750	29.5	0.780
Medium	80.3	<0.062	4.32	0.510	23.5	<0.625
High	83.7	<0.062	4.69	0.680	29.5	1.08
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	0.192**
			Liver			
Low	100	0.176	19.4	19.8	444	<0.625
Medium	103	0.746	19.2	18.3	442	—
High	103	1.17	18.2	16.4	419	<0.625
LSD	n.s.	0.226**	n.s.	2.1*	n.s.	n.s.

*,** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 58. Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. Samples taken 8 weeks after hatching.

Diet	Chemical Element				
	Ca	Na	Mg	K	P
	--% fat-free dry weight--				
			Breast Muscle		
Low	0.022	0.150	0.136	1.63	0.940
Medium	0.026	0.137	0.138	1.63	0.872
High	0.059	0.143	0.132	1.59	0.951
LSD	0.028*	n.s.	n.s.	n.s.	n.s.
			Gizzard		
Low	0.053	0.373	0.074	1.38	0.563
Medium	0.057	0.383	0.077	1.39	0.596
High	0.051	0.383	0.072	1.45	0.574
LSD	n.s.	n.s.	n.s.	n.s.	n.s.
			Kidney		
Low	0.039	0.722	0.098	1.07	1.13
Medium	0.052	0.741	0.107	1.09	1.14
High	0.043	0.809	0.107	1.20	1.12
LSD	0.009*	n.s.	n.s.	n.s.	n.s.
			Leg Muscle		
Low	0.024	0.310	0.122	1.76	0.776
Medium	0.020	0.290	0.121	1.71	0.770
High	0.020	0.323	0.125	1.80	0.798
LSD	n.s.	n.s.	n.s.	n.s.	n.s.
			Liver		
Low	0.017	0.361	0.100	1.27	1.13
Medium	0.018	0.362	0.104	1.31	1.21
High	0.017	0.368	0.098	1.26	1.06
LSD	n.s.	n.s.	n.s.	n.s.	n.s.

*,** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 59. Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. Samples taken 20 weeks after hatching.

Diet	Chemical Element					
	Zn	Cd	Cu	Mn	Fe	Pb
	mg/kg fat-free dry weight					
			Breast Muscle			
Low	24.2	<0.062	1.60	0.605	15.6	<0.625
Medium	19.8	0.0915	1.98	0.818	14.7	<0.625
High	16.4	0.109	1.90	0.762	15.3	<0.625
LSD	n.s.	n.s.	n.s.	n.s.	0.6*	n.s.
			Gizzard			
Low	108	0.872	9.08	14.3	178	<0.625
Medium	114	4.69	10.5	12.7	183	<0.625
High	116	6.90	8.48	12.8	184	<0.625
LSD	n.s.	1.14**	1.36*	n.s.	n.s.	n.s.
			Kidney			
Low	109	0.986	14.0	15.7	465	<0.625
Medium	116	7.64	15.0	13.2	505	<0.625
High	128	13.6	15.4	14.6	468	<0.625
LSD	14**	1.82**	0.9**	n.s.	n.s.	n.s.
			Leg Muscle			
Low	73.6	0.0928	7.78	0.902	44.8	1.17
Medium	83.3	0.0738	4.58	1.14	51.4	<0.625
High	75.2	0.121	4.15	0.990	52.3	<0.625
LSD	n.s.	n.s.	n.s.	n.s.	6.2*	0.584**
			Liver			
Low	119	0.352	17.9	17.8	788	0.848
Medium	115	2.17	17.0	16.1	749	<0.625
High	113	3.55	17.0	16.5	667	<0.625
LSD	n.s.	0.776**	n.s.	n.s.	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 60. Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. Samples taken 20 weeks after hatching.

Diet	Chemical Element				
	Ca	Na	Mg	K	P
	% fat-free dry weight				
			Breast Muscle		
Low	0.008	0.149	0.120	1.42	0.915
Medium	0.014	0.167	0.123	1.32	0.882
High	0.011	0.154	0.118	1.36	0.900
LSD	n.s.	n.s.	n.s.	n.s.	n.s.
			Gizzard		
Low	0.050	0.355	0.069	1.13	0.575
Medium	0.040	0.351	0.070	1.26	0.589
High	0.049	0.356	0.067	1.21	0.616
LSD	n.s.	n.s.	n.s.	n.s.	n.s.
			Kidney		
Low	0.032	0.806	0.104	1.32	1.40
Medium	0.041	0.770	0.100	1.21	1.36
High	0.035	0.831	0.092	1.17	1.35
LSD	n.s.	n.s.	0.008**	0.096*	n.s.
			Leg Muscle		
Low	0.024	0.309	0.109	1.44	0.892
Medium	0.018	0.316	0.111	1.37	0.877
High	0.020	0.303	0.106	1.42	0.882
LSD	n.s.	n.s.	n.s.	n.s.	n.s.
			Liver		
Low	0.023	0.347	0.101	1.30	1.35
Medium	0.031	0.337	0.101	1.18	1.37
High	0.023	0.335	0.088	1.16	1.24
LSD	n.s.	n.s.	n.s.	n.s.	n.s.

*,** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 61. Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. Samples taken 50 weeks after hatching.

Diet	Chemical Element					
	Zn	Cd	Cu	Mn	Fe	Pb
	mg/kg fat-free dry weight					
				Brain		
Low	50.9	<0.062	13.9	2.66	125	<0.625
Medium	50.0	<0.062	13.2	2.29	92.6	<0.625
High	51.8	0.070	14.5	2.47	81.2	<0.625
LSD	n.s	n.s.	n.s.	0.28*	25.6*	n.s.
				Breast Muscle		
Low	18.8	0.134	1.20	0.136	15.1	<0.625
Medium	19.4	0.0948	1.22	0.345	12.9	<0.625
High	21.0	0.112	1.51	0.422	21.3	<0.625
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
				Crop		
Low	72.5	<0.062	4.86	8.63	63.4	<0.625
Medium	83.6	0.198	5.00	16.6	93.2	<0.625
High	89.7	0.329	6.28	26.0	126	4.43
LSD	n.s.	0.100**	n.s.	n.s.	37.6*	n.s.
				Duodenum		
Low	86.8	0.432	7.85	7.93	188	<0.625
Medium	87.4	1.31	7.85	7.19	208	<0.625
High	87.1	2.18	8.28	8.53	202	<0.625
LSD	n.s.	0.736**	n.s.	n.s.	n.s.	n.s.
				Feathers		
Low	238	0.170	21.4	3.42	112	13.2
Medium	202	0.165	8.30	2.54	83.1	12.2
High	217	0.218	11.1	3.12	79.8	6.89
LSD	n.s.	n.s.	7.62*	n.s.	20.9*	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 61. Continued Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. Samples taken 50 weeks after hatching.

Diet	Zn	Cd	Cu	Mn	Fe	Pb
	Chemical Element					
	mg/kg fat-free dry weight					
Femur Bone						
Low	229	<0.062	0.985	19.0	135	<0.625
Medium	256	<0.062	0.743	16.0	115	<0.625
High	272	0.0735	0.777	17.0	141	<0.625
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Gizzard						
Low	128	1.03	4.55	3.84	186	0.355
Medium	125	4.27	4.80	3.40	181	<0.625
High	132	9.34	5.42	3.78	188	0.658
LSD	n.s.	3.33**	n.s.	n.s.	n.s.	n.s.
Gizzard Lining						
Low	22.5	1.39	33.4	21.7	85.8	1.12
Medium	24.7	8.78	35.8	18.5	93.9	1.45
High	29.7	13.6	56.0	28.2	74.6	1.73
LSD	n.s.	5.79**	13.2*	n.s.	n.s.	n.s.
Heart						
Low	107	<0.062	16.2	2.80	240	0.798
Medium	103	<0.062	16.0	2.60	217	<0.625
High	98.9	0.188	16.0	2.75	234	<0.625
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Kidney						
Low	118	4.61	12.9	10.1	359	<0.625
Medium	125	21.8	13.1	11.6	382	<0.625
High	142	36.8	13.8	13.2	330	<0.625
LSD	n.s.	4.8**	n.s.	2.4**	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 61. Continued Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. Samples taken 50 weeks after hatching.

Diet	Zn	Cd	Cu	Mn	Fe	Pb
	Chemical Element					
	mg/kg fat-free dry weight					
Leg Muscle						
Low	116	0.111	4.05	0.874	81.0	0.836
Medium	118	0.163	3.70	0.762	64.0	<0.625
High	108	0.110	4.06	0.760	62.0	<0.625
LSD	n.s.	0.039*	n.s.	n.s.	n.s.	n.s.
Liver						
Low	128	0.898	16.0	9.40	337	0.998
Medium	138	3.57	14.7	13.0	303	<0.625
High	134	6.18	16.2	11.9	257	<0.625
LSD	n.s.	0.190**	n.s.	n.s.	n.s.	n.s.
Lung						
Low	48.4	<0.062	2.19	1.96	771	<0.625
Medium	51.6	0.128	2.29	2.20	809	<0.625
High	49.4	0.319	2.43	2.23	780	<0.625
LSD	n.s.	0.140**	n.s.	n.s.	n.s.	n.s.
Pancreas						
Low	115	0.299	6.85	13.0	182	<1.00
Medium	127	1.85	6.15	13.5	164	<1.00
High	129	2.90	6.01	14.0	142	<1.00
LSD	n.s.	0.586**	n.s.	n.s.	n.s.	n.s.
Proventriculus						
Low	89.6	0.233	13.6	11.3	152	0.728
Medium	72.4	0.800	11.6	9.23	110	<0.625
High	77.2	1.32	12.5	10.1	108	<0.625
LSD	n.s.	0.316**	n.s.	n.s.	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 61. Continued Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. Samples taken 50 weeks after hatching.

Diet	Chemical Element					
	Zn	Cd	Cu	Mn	Fe	Pb
	mg/kg fat-free dry weight					
			Spleen			
Low	83.2	0.349	4.56	2.25	892	<1.00
Medium	88.8	1.58	4.76	2.27	814	<1.00
High	86.3	1.56	4.62	2.03	841	<1.00
LSD	3.1*	0.981*	n.s.	n.s.	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

It is noteworthy that for hens switched from low- to high-Cd diets, tissues that were notable accumulators of Cd gained as much of the metal as was lost by the same tissues in hens that were switched from high- to low-Cd diets. Changes in concentrations of other transition or heavy metals were either not related to Cd levels in diets or were not supported by concentration changes of these metals in similar tissues collected earlier and later than 72 weeks.

As can be seen in Table 64, concentrations of Cd were significantly increased in 80 weeks crop, proventriculus, muscular gizzard, gizzard lining, and duodenum tissues. Furthermore, relatively large changes in concentrations occurred when hens were switching from one dietary-Cd level to another. At 80 weeks, enhanced concentrations of Cd in liver, kidney, pancreas, and spleen tissues paralleled levels of the metal in diets, although differences in concentrations of the latter tissues were small in comparison to changes in kidney. It was unlikely that concentration of Cd in heart and lungs was affected by diets, because difference in concentration was dependent on the use of one-half the lowest detectable level to show significance. The same is true for leg muscle tissue. No differences were found in breast muscle. A small, but significant enhancement of Cd concentrations in femur bone with higher dietary-Cd levels was found at 80 weeks. Concentrations of Cd in brain and feathers were unaffected by dietary-Cd levels, although an insignificant trend for higher levels in feathers was observed. Concentrations of Cd were significantly changed in 80 week liver, kidney, pancreas, and spleen tissues when hens were switched to different diets, but only liver and kidney tissues had markedly higher or lower Cd concentrations as a result of reciprocal changes in dietary-Cd levels.

In a comparison of Cd concentrations in tissues of 50- and 80-week old hens, enhanced levels with age occurred only in kidney tissues. During the 30-week interval, Cd concentrations in kidney were increased a little less

Table 62. Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. Samples taken 50 weeks after hatching.

Diet	Chemical Element				
	Ca	Na	Mg	K	P
	---% fat-free dry weight---				
			Breast Muscle		
Low	0.0175	0.176	0.112	1.28	0.717
Medium	0.0126	0.173	0.114	1.44	0.810
High	0.0113	0.187	0.112	1.43	0.790
LSD	n.s.	n.s.	n.s.	n.s.	n.s.
			Gizzard		
Low	0.0791	0.512	0.0663	1.46	0.430
Medium	0.0527	0.436	0.0663	1.38	0.379
High	0.0323	0.447	0.0778	1.51	0.421
LSD	n.s.	0.052*	n.s.	n.s.	n.s.
			Gizzard Lining		
Low	0.183	0.0894	0.0113	0.120	0.277
Medium	0.116	0.0753	0.0099	0.120	0.322
High	0.178	0.0855	0.0160	0.129	0.306
LSD	n.s.	n.s.	n.s.	n.s.	n.s.
			Kidney		
Low	0.0646	0.835	0.0908	1.37	1.25
Medium	0.0612	0.992	0.0911	1.40	1.14
High	0.0503	0.941	0.0859	1.30	1.21
LSD	n.s.	n.s.	n.s.	n.s.	n.s.
			Leg Muscle		
Low	0.0248	0.378	0.0975	1.53	0.813
Medium	0.0240	0.340	0.0971	1.46	0.670
High	0.0246	0.364	0.101	1.45	0.730
LSD	n.s.	n.s.	n.s.	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 62. Continued Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. Samples taken 30 weeks after hatching.

Diet	Chemical Element				
	Ca	Na	Mg	K	P
	% fat-free dry weight				
			Liver		
Low	0.0212	0.393	0.0863	1.30	1.14
Medium	0.0298	0.345	0.0874	1.32	1.12
High	0.0284	0.345	0.0833	1.31	1.05
LSD	n.s.	n.s.	n.s.	n.s.	n.s.

*, ** significant at 0.50 and 0.01, respectively.
n.s. = non-significant F-test.

than two-fold, regardless of the concentration of Cd in the diet. In other tissues that accumulated Cd, concentrations appeared to have reached an equilibrium with dietary levels of the metal at 50 weeks of age and thus, remained unchanged with time. For hens that were switched from high- to low-Cd diets at 50 weeks, only kidney tissues contained higher concentrations of Cd 30 weeks later.

Clinical Parameters--

There was some indication of low packed cell volumes (PCVs) in the high Cd group (Table 65), but all of the individual data will require collective evaluation. Variations in mean corpuscular volume (MCV) were frequently more pronounced within treatment group, with distinctly different populations, than among group means (Table 66). It appeared that the high Cd group may have a distorted neutrophil/lymphocyte ratio at 8 weeks, but it later became evident that this parameter, too, was quite variable within treatment groups (Table 67). Counting avian leukocytes is an extremely arduous and time-consuming task, so this procedure was discontinued in the 70 and 80 week birds because of the lack of clear patterns. Serum chemistries (Table 68) also failed to show consistent trends. There was, however, a slight tendency for the high dose group to contain a greater frequency of birds with "low" serum calcium; this could conceivably be related to Cd interference with Ca metabolism, but the test employed unfortunately had a limited range.

Relative Organ Weights--

The liver and kidney tended to be slightly larger in the higher Cd groups, but the tendency was rather weak and inconsistent (Table 69). The gizzard did accumulate high concentrations of Cd early in the study. Anke et al. (1970) reported epithelial changes in Gizzards from Cd treated chickens which were reminiscent of Zn deficiency. In an acutely Cd-poisoned chick we found the gizzard was visibly enlarged, so this organ may be particularly susceptible to Cd. Nevertheless, by 72 weeks the differences disappeared, indicating that

Table 63. Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. After 50 weeks, subgroups from those hens being fed the low- and high-cadmium diets were switched to high- and low-cadmium diets, respectively. Samples taken 72 weeks after hatching.

Diet	Chemical Element					
	Zn	Cd	Cu	Mn	Fe	Pb
	mg/kg fat-free dry weight					
			Breast Muscle			
Low	19.8	0.063	1.50	0.607	15.7	<0.625
Medium	19.9	0.076	1.41	0.551	15.2	<0.625
High	19.9	0.067	1.51	0.460	15.7	<0.625
Low-High	19.7	<0.062	1.53	0.437	13.8	<0.625
High-Low	18.9	0.075	1.37	0.531	16.3	<0.625
LSD	n.s.	0.021**	n.s.	0.112*	n.s.	n.s.
			Gizzard			
Low	134	1.06	5.71	4.68	226	<1.00
Medium	130	6.77	5.10	4.25	212	<1.00
High	131	11.2	5.80	4.40	220	<1.00
Low-High	132	7.54	5.54	3.76	223	<1.00
High-Low	118	3.87	4.80	4.69	197	<1.00
LSD	9**	2.05**	n.s.	n.s.	n.s.	n.s.
			Gizzard Lining			
Low	16.7	1.36	39.0	21.4	97.0	<1.00
Medium	22.3	8.04	36.6	23.8	104	<1.00
High	28.5	14.3	38.7	22.5	93.4	1.89
Low-High	24.0	12.0	38.3	22.4	79.8	1.17
High-Low	18.9	3.98	36.6	30.5	84.9	<1.00
LSD	6.7*	2.97**	n.s.	n.s.	n.s.	0.792*
			Kidney			
Low	124	8.32	13.6	13.0	444	<1.00
Medium	142	42.2	14.6	12.0	436	<1.00
High	150	64.4	16.1	12.3	412	<1.00
Low-High	135	19.5	23.7	11.8	423	<1.00
High-Low	134	44.4	14.9	13.1	433	<1.00
LSD	n.s.	15.8**	n.s.	n.s.	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 63. Continued

Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. After 50 weeks, subgroups from those hens being fed the low- and high-cadmium diets were switched to high- and low-cadmium diets, respectively. Samples taken 72 weeks after hatching.

Diet	Chemical Element					
	Zn	Cd	Cu	Mn	Fe	Pb
	mg/kg fat-free dry weight					
			Leg Muscle			
Low	114	<0.062	3.77	1.08	62.4	<0.625
Medium	110	0.111	3.85	0.880	59.3	<0.625
High	104	0.136	3.27	1.04	55.9	<0.625
Low-High	113	0.081	3.90	0.815	69.4	<0.625
High-Low	106	0.124	0.313	0.834	64.2	<0.625
LSD	n.s.	0.037**	0.712**	n.s.	n.s.	n.s.
			Liver			
Low	119	1.48	15.7	11.7	397	<1.00
Medium	150	4.06	16.8	9.48	374	<1.00
High	147	5.81	17.0	10.3	452	<1.00
Low-High	139	2.50	15.5	11.8	573	<1.00
High-Low	109	4.49	13.9	9.15	305	<1.00
LSD	28*	1.80**	n.s.	n.s.	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 64. Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. After 50 weeks, subgroups from those hens being fed the low- and high-cadmium diets were switched to high- and low-cadmium diets, respectively. Samples taken 80 weeks after hatching.

Diet	Chemical Element					
	Zn	Cd	Cu	Mn	Fe	Pb
	mg/kg fat-free dry weight					
				Brain		
Low	50.8	0.101	12.2	1.60	109	2.05
Medium	48.3	<0.092	11.7	1.51	105	1.77
High	54.7	<0.092	12.2	1.66	112	1.93
Low-High	50.1	<0.092	11.4	1.70	103	1.72
High-Low	52.4	<0.092	12.3	1.62	109	1.89
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
				Breast Muscle		
Low	19.8	<0.062	1.76	0.351	17.8	<0.625
Medium	18.4	<0.062	1.71	0.316	16.2	<0.625
High	19.3	<0.062	1.64	0.263	14.4	<0.625
Low-High	18.4	<0.062	1.44	0.381	14.0	<0.625
High-Low	19.0	<0.062	1.63	0.427	16.6	<0.625
LSD	n.s.	n.s.	n.s.	0.109**	n.s.	n.s.
				Crop		
Low	79.9	0.243	5.18	1.82	63.5	<0.830
Medium	77.8	0.400	5.91	4.60	74.8	0.922
High	86.9	0.528	5.84	4.43	75.3	<0.830
Low-High	73.0	0.294	4.36	3.93	62.1	<0.830
High-Low	81.6	0.458	5.79	3.30	82.6	<0.830
LSD	8.2*	0.078**	n.s.	n.s.	n.s.	0.313**
				Duodenum		
Low	92.2	0.523	7.48	5.66	213	<1.00
Medium	94.4	1.23	7.20	5.28	184	1.05
High	106	1.98	8.13	5.52	279	1.13
Low-High	99.7	1.33	7.55	5.90	209	2.03
High-Low	94.4	0.612	7.50	6.05	250	<1.00
LSD	n.s.	0.646**	n.s.	n.s.	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 64. Continued

Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. After 50 weeks, subgroups from those hens being fed the low- and high-cadmium diets were switched to high- and low-cadmium diets, respectively. Samples taken 80 weeks after hatching.

Diet	Chemical Element					
	Zn	Cd	Cu	Mn	Fe	Pb
	mg/kg fat-free dry weight					
			Feathers			
Low	153	0.073	6.17	1.60	41.3	4.44
Medium	190	0.100	6.51	1.56	41.4	6.65
High	219	0.155	6.58	2.03	39.5	4.87
Low-High	188	0.118	6.92	1.55	36.1	4.04
High-Low	235	0.108	6.99	3.42	44.4	5.04
LSD	n.s.	n.s.	n.s.	1.50**	n.s.	n.s.
			Femur Bone			
Low	206	0.145	1.17	9.74	84.4	1.49
Medium	233	0.152	1.10	8.44	73.1	1.58
High	268	0.221	1.08	8.89	87.3	2.15
Low-High	257	0.162	0.950	8.16	66.7	1.70
High-Low	246	0.176	1.24	8.29	79.8	1.79
LSD	n.s.	0.046*	n.s.	n.s.	n.s.	0.41*
			Gizzard			
Low	109	1.11	4.72	4.13	167	1.19
Medium	117	6.06	5.18	3.88	204	<1.00
High	116	9.96	5.02	3.46	213	1.08
Low-High	120	9.00	6.25	4.04	184	<1.00
High-Low	107	3.22	4.32	4.07	196	1.03
LSD	n.s.	2.33**	n.s.	n.s.	30**	n.s.
			Gizzard Lining			
Low	15.5	2.08	38.2	11.0	79.7	1.05
Medium	17.5	9.14	37.5	13.2	82.4	<1.00
High	18.4	15.0	34.9	10.9	88.9	1.63
Low-High	20.6	14.9	32.8	15.6	94.7	1.02
High-Low	16.0	3.96	33.3	12.9	81.5	1.06
LSD	n.s.	2.82**	n.s.	n.s.	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 64. Continued Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. After 50 weeks, subgroups from those hens being fed the low- and high-cadmium diets were switched to high- and low-cadmium diets, respectively. Samples taken 80 weeks after hatching.

Diet	Chemical Element					
	Zn	Cd	Cu	Mn	Fe	Pb
	mg/kg fat-free dry weight					
			Heart			
Low	101	<0.077	15.4	2.35	217	<0.775
Medium	104	<0.077	15.5	2.44	227	<0.775
High	105	0.114	16.3	2.45	243	<0.775
Low-High	108	<0.077	16.4	2.60	225	<0.775
High-Low	107	0.090	15.8	2.55	235	<0.775
LSD	n.s.	0.051**	n.s.	n.s.	n.s.	n.s.
			Kidney			
Low	124	9.52	14.3	12.7	281	<1.00
Medium	144	45.8	15.0	12.3	264	<1.00
High	155	69.5	14.6	12.2	234	<1.00
Low-High	133	21.8	13.8	11.3	269	<1.00
High-Low	149	51.3	14.3	11.5	288	<1.00
LSD	21**	9.57**	n.s.	n.s.	n.s.	n.s.
			Leg Muscle			
Low	103	<0.062	4.02	0.767	68.1	<0.625
Medium	105	0.113	3.77	0.727	68.2	<0.625
High	96.4	0.131	3.42	0.757	63.4	<0.625
Low-High	105	<0.062	3.41	0.693	61.3	<0.625
High-Low	106	0.115	3.52	0.733	70.3	<0.625
LSD	n.s.	0.045**	n.s.	n.s.	n.s.	n.s.
			Liver			
Low	142	1.43	18.8	16.3	740	<1.00
Medium	179	4.86	19.1	13.8	567	<1.00
High	177	6.66	18.7	15.5	500	<1.00
Low-High	179	3.93	19.2	17.0	585	<1.00
High-Low	146	4.20	17.3	14.3	665	<1.00
LSD	n.s.	1.64**	n.s.	n.s.	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 64. Continued

Concentrations of selected elements in various tissues of hens fed low-, medium-, and high-cadmium diets formulated from corn and soybeans grown on sludge-amended soil. After 50 weeks, subgroups from those hens being fed the low- and high-cadmium diets were switched to high- and low-cadmium diets, respectively. Samples taken 80 weeks after hatching.

Diet	Chemical Element					
	Zn	Cd	Cu	Mn	Fe	Pb
	mg/kg fat-free dry weight					
			Lung			
Low	63.9	<0.098	2.16	1.13	875	<1.34
Medium	58.8	0.149	1.84	1.03	1060	<1.34
High	61.2	0.277	2.20	0.855	1350	<1.34
Low-High	65.2	0.126	1.94	1.25	1200	1.53
High-Low	54.3	0.234	2.37	1.18	868	<1.34
LSD	n.s.	0.154**	n.s.	n.s.	303**	n.s.
			Pancreas			
Low	112	0.373	4.18	6.49	147	<0.954
Medium	111	1.86	4.14	6.69	93.8	<0.954
High	144	2.78	4.33	6.91	162	<0.954
Low-High	121	1.11	4.20	8.49	164	<0.954
High-Low	112	2.11	3.69	7.93	138	<0.954
LSD	n.s.	0.609**	n.s.	n.s.	n.s.	n.s.
			Proventriculus			
Low	70.3	0.289	14.3	10.5	108	<0.661
Medium	70.8	1.16	18.8	10.6	96.2	<0.661
High	74.6	1.83	19.5	10.2	108	1.20
Low-High	75.4	0.853	24.9	11.2	144	<0.661
High-Low	76.2	1.30	13.4	11.1	125	<0.661
LSD	n.s.	0.391**	6.9**	n.s.	n.s.	n.s.
			Spleen			
Low	83.4	0.358	5.08	1.54	867	<2.64
Medium	85.9	1.19	6.16	1.52	935	<2.64
High	84.3	1.49	8.84	1.56	874	4.30
Low-High	90.5	0.971	9.86	1.72	982	<2.64
High-Low	85.0	1.41	6.84	1.67	941	<2.64
LSD	n.s.	0.463**	3.41**	n.s.	n.s.	n.s.

*, ** = significant at 0.05 and 0.01, respectively.
n.s. = non-significant F-test.

Table 65. Hematological parameters in white leghorn hens having received sludge-fertilized corn-soybean diets from one week of age.

Age and Relative Dietary Cd	(n)	PCV[1)]	RBC[2)]	Hb[3)]
8 Weeks				
Low	(16)	32.3 ± 1.5 (29.5-34.5)	-	-
Medium	(15)	32.0 ± 2.0 (29-37)	-	-
High	(13)	31.4 ± 1.7 (28.5-34.5)	-	-
20 Weeks				
Low	(8)	32.4 ± 2.0 (31-36)	-	-
Medium	(8)	31.1 ± 2.9 (27-35)	-	-
High	(8)	32.5 ± 4.1 (27.5-39)	-	-
50 Weeks				
Low	(9)	33.1 ± 3.4 (28-39)	2.1 ± 0.35 (1.82-2.93)	8.5 ± 1.1 (7.0-10.4)
	(1)	26	2.04	7.4
Medium	(10)	29.9 ± 4.0 (25-37.5)	2.17 ± 0.31 (1.72-2.67)	8.3 ± 1.4 (7.0-11.5)
High	(9)	28.0 ± 3.4 (22-32.5)	2.02 ± 0.29 (1.65-2.66)	8.2 ± 0.6 (7.6-9.5)
70 Weeks				
Low	(10)	31.2 ± 3.5 (26-36)	2.46 ± 0.45 (2.13-3.48)	9.6 ± 1.4 (7.6-11.8)
L→H	(9)	27.4 ± 3.5 (22-33)	2.19 ± 0.25 (1.70-2.59)	8.5 ± 0.9 (7.0-9.6)
	(1)[4)]	20.5	1.44	5.8

(continued)

Table 65. (continued)

Age and Relative Dietary Cd (n)		PCV[1]	RBC[2]	Hb[3]
70 Weeks (continued)				
Medium	(10)	30.0 ± 4.2 (24-38)	2.06 ± 0.29[5] (1.69-2.33)	8.2 ± 1.2[5] (6.8-9.8)
High	(10)	30.4 ± 3.7 (26-37.5)	2.28 ± 0.32[6] (1.67-2.67)	8.9 ± 0.9[6] (7.6-10.0)
H→L	(10)	30.8 ± 2.3 (27.5-34.5)	2.67 ± 0.16[5] (2.54-2.91)	9.8 ± 0.4[5] (9.2-10.0)
80 Weeks				
Low	(10)	29.7 ± 3.6 (24-34)	2.06 ± 0.31 (1.65-2.49)	9.1 ± 1.1 (7.0-10.7)
L→H	(10)	30.2 ± 3.1 (26-37)	2.19 ± 0.58 (1.75-3.54)	9.6 ± 1.1 (8.2-11.8)
Medium	(10)	28.4 ± 3.7 (22-35)	1.99 ± 0.32 (1.63-2.61)	8.5 ± 1.2 (6.2-10.4)
High	(10)	27.6 ± 4.0 (20.5-32)	1.86 ± 0.36[7] (1.31-2.28)	8.8 ± 1.4[7] (7.4-11.2)
H→L	(9)	28.2 ± 1.9 (26-31.5)	1.91 ± 0.33 (1.48-2.48)	9.0 ± 0.8 (8.2-10.4)

[1] Packed cell volume (%)

[2] Red blood cells ($10^6/\mu l$)

[3] Hemoglobin (g/dl)

[4] Liver hemorrhage & necrosis

[5] n=4

[6] n=7

[7] n=6

Table 66. Red blood cell characteristics in white leghorn hens having received sludge-fertilized corn-soybean diets from one week of age.

Age and Relative Dietary Cd	Mean Corpuscular Volume		Mean Corpuscular Hemoglobin Conc.		Mean Corpuscular Hemoglobin	
	n*	fl ± S.D.	n	g/dl ± S.D.	n	pg ± S.D.
50 Weeks						
Low	9	152 ± 19	10	28.7 ± 1.7	10	39.2 ± 3.8
	(6)	163 ± 13				
	(3)	131 ± 3				
Medium	9	139 ± 13	10	29.3 ± 1.9	10	38.4 ± 4.1
	(6)	146 ± 8				
	(3)	124 ± 4				
High	9	146 ± 26	9	29.5 ± 1.6	9	41.2 ± 4.9
	(7)	157 ± 18				
	(2)	110 ± 3				
70 Weeks						
Low	7	135 ± 14	8	32.4 ± 1.2	7	41.2 ± 4.9
					1	28.7
Medium	4	136 ± 17	4	32.9 ± 5.4	4	40.0 ± 4.0
High	7	131 ± 17	7	33.7 ± 1.7	7	39.4 ± 4.6
	(2)	156 ± 0				
	(5)	122 ± 5				
H→L	4	121 ± 14	4	32.6 ± 1.3	4	36.7 ± 1.9
L→H	10	127 ± 10	10	32.9 ± 1.1	10	39.0 ± 1.7
80 Weeks						
Low	10	161 ± 20	10	30.7 ± 1.8	10	45.0 ± 7.5
Medium	10	159 ± 20	10	29.9 ± 2.0	10	43.1 ± 6.6
High	5	159 ± 10	6	31.6 ± 2.3	6	48.0 ± 5.3
	1	221				
H→L	7	167 ± 12	9	31.8 ± 1.7	9	47.8 ± 6.5
	1	206				
	1	125				
L→H	9	167 ± 19	10	32.0 ± 1.9	9	48.0 ± 7.5
	1	95			1	27.7

* Definite outliers are listed separately. If total group is subdivided, n is parenthetic (n) for subgroups.

the gizzard may adapt to the Cd insult. The consistency of the brain:body ratio (Table 70) indicated that these differences were not due to body weight changes.

Liver Parameters--

The livers of caged layers tend to accumulate large amounts of fat, especially when full egg production is approached. This fatty liver is frequently friable, inflicted with small hemorrhages and occasionally necrotic in small areas. In the 8, 20, and 50 week birds, histological examination revealed fatty infiltration or ballooning degeneration. There was also some degree of cell swelling. The histological evaluation generally paralleled gross observations and gravimetric determinations of % liver fat (Table 71). Lipofuschin pigment accumulation was assessed in pooled samples of liver at 50, 70, and 80 weeks. In general, the changes in liver morphology, fat content, and pigment accumulation were age related but not influenced by dietary Cd.

Likewise, there were age related changes in microsomal protein which were not influenced by dietary Cd. Hepatic microsomal cytochrome P-450 was quite variable, but apparently depressed by the high dietary Cd (Table 72). The variability of these values, however, is of some concern and the individual assays (spectrophotometric tracings) must be re-evaluated. There was little effect of age or dietary Cd on microsomal NADPH oxidase (Table 72).

The O-dealkylation of p-nitrophenetole (pNP) by hepatic microsomes did not vary significantly with dietary Cd, but there were age changes (Table 73). The specific activity is listed for 2 pNP concentrations. Although complete kinetic plots were attempted, these data must also be re-evaluated. There appeared to be slightly higher affinity (low substrate) O-dealkylation activity in the high-Cd birds in spite of decreased amounts of cytochrome P-450 (Table 72). The low affinity enzyme (high substrate concentration) was not affected. If the high affinity O-dealkylase activity is expressed per nmole P-450, the differences will probably be significant statistically--the biochemical significance is unclear.

Conclusions

1. Because laying hens consume more feed per unit body weight than other animals, it is concluded that feed grains produced on soils amended with sewage sludge, containing no higher Cd concentrations than those in MSD of Chicago sludges and applied at recommended N rates, will not affect animal health and performance.

2. At levels of Cd that are possible to obtain in the seed or grain of crops, without serious reductions in yields, there is no evidence that Cd would interfere with the assimilation of other nutrients by animals.

3. If levels of Cd in soybeans and corn grain grown on sludge-amended soils presents a potential hazard to human food-chains, it is a nominal one. Concentrations of Cd in eggs were not affected by levels in corn grain and soybeans. Muscle tissues were unaffected by Cd levels in diets. Considering offal organs used as human foods, Cd accumulated at higher concentrations by order of listing in liver, gizzard, and kidney. But on a fresh weight basis

(including fat and water) the highest concentration of Cd in liver was about 1.45 mg/kg and well within the upper range reported in animal livers produced under normal management practices (Kreuzer et al., 1977). On a fresh weight basis, the highest level of Cd in any tissue was 12.2 mg/kg in kidney. It therefore appears that the consumption of gizzards and kidneys would present about the same health hazard from Cd as diets that include shellfish.

4. The direct consumption of corn grain and soybeans by human animals must present an exceedingly small potential health hazard. On a per unit body weight basis, man does not live long enough to consume as much biologically incorporated Cd as did laying hens.

Table 67. Leukocyte populations in white leghorn hens having received sludge-fertilized corn-soybean diets from one week of age.

Age and Relative Dietary Cd	(n)[1]	Mean ± S.D. % Total Leukocytes				
		Segmented Neutrophils	Lymphocytes	Monocytes	Eosinophils	Basophils
8 Weeks						
Low	(4)	20.5 ± 2.1	72.5 ± 3.9	1.0 ± 0.6	1.0 ± 0	5.0 ± 2.2
(range)		(18-23)	(69-78)	(0-2)	(1-1)	(2-7)
Medium	(3)	14.7 ± 4.7	77.7 ± 4.9	0.3 ± 0.6	1.3 ± 1.5	6.0 ± 1.4
(range)		(11-20)	(72-81)	(0-1)	(0-3)	(5-7)
High	(3)	5.7 ± 2.1	88.3 ± 3.8	0.3 ± 0.6	0.7 ± 1.2	5.0 ± 3.0
(range)		(4-8)	(84-91)	(0-1)	(0-2)	(2-8)
	(1)	31	64	0	4	1
20 Weeks						
Low	(8)	39.9 ± 5.2	53.6 ± 9.7	0.4 ± 0.7	1.4 ± 1.3	4.8 ± 4.5
	(3)	12.7 ± 3.5	80.7 ± 9.0	0	2.0 ± 2.0	4.7 ± 5.5
	(1)	68	21	0	6	5
Medium	(8)	35.9 ± 9.3	56.6 ± 8.2	0.5 ± 1.1	2.8 ± 2.2	4.2 ± 5.2
	(1)	20	73	1	1	5
	(1)	66	28	0	0	6
High	(9)	42.7 ± 9.4	52.2 ± 9.9	0.1 ± 0.3	0.7 ± 1.4	4.3 ± 3.0
	(3)	13.0 ± 4.4	82.3 ± 7.1	0	1.3 ± 2.3	2.3 ± 1.5
50 Weeks						
Low	(7)	37.0 ± 11.1	52.7 ± 14.0	4.6 ± 3.2	1.1 ± 1.1	4.4 ± 3.8
(range)		(23-52)	(27-70)	(1-10)	(0-3)	(0-11)
	(1)	19	73	7	0	1
Medium	(8)	33.5 ± 13.3	57.4 ± 13.9	4.1 ± 3.4	0.6 ± 1.1	4.1 ± 2.7
(range)		(13-49)	(38-74)	(1-10)	(0-3)	(0-8)
High	(8)	31.4 ± 4.0	58.4 ± 7.8	2.9 ± 2.7	0.6 ± 1.2	5.6 ± 6.8
(range)		(25-37)	(40-65)	(0-7)	(0-3)	(0-21)

1) Treatment groups were occasionally subdivided to emphasize obvious out-liers. The bird at 50 weeks low dose, e.g., was separated due to a large tumor.

Table 68. Serum chemistries from white leghorn hens having received sludge-fertilized corn-soybean diets from one week of age.

Age and Relative Dietary Cd	(n)	Mean ± S.D. for Serum[1]									
		CRT	TP	ALB	P	AP	CPK	GPT	LDH	Ca	GLU
8 Weeks											
Low	(12)	1.3 ±0.2	3.9 ±0.7	-	7.5 ±0.9	427 ±85	146 ±58	70 ±18	431 ±108	11.3 ±0.6	286 ±39
Medium	(12)	1.5 ±0.2	3.6 ±0.5	-	7.4 ±0.9	456 ±94	146 ±36	71 ±14	445 ±90	11.6 ±0.7	267 ±16
High	(11)	1.3 ±0.3	3.4 ±0.5	-	7.4 ±1.2	469 ±93	197 ±94	59 ±20	458 ±108	11.4 ±0.5	284 ±22
20 Weeks											
Low	(8)	1.3 ±0.5	5.2 ±1.1	-	7.3 ±1.8	>70	185 ±117	99 ±22	>350	>14	204[2] ±125
Medium	(8)	1.6 ±0.7	6.0 ±1.5	-	8.8 ±1.2	>70	161 ±89	122 ±53	>350	>14	219[2] ±121
High	(8)	1.2 ±0.4	4.5 ±1.4	-	7.3 ±1.8	>70	154 ±83	111 ±23	>350	<14[3]	172[2] ±112
50 Weeks											
Low	(8)	-	6.3 ±1.6	-	-	>70	-	58 ±15	-	-	-
Medium	(8)	-	5.9 ±1.1	-	8.0 ±2.4	>70	-	66 ±16	-	-	-
High	(4)	1.0 ±0.4	5.8 ±1.4	-	5.9 ±2.3	>70	460 ±145	58 ±24	-	-	-
70 Weeks											
Low	(7)	0.8 ±0.2	5.3 ±0.8	2.33 ±0.29	6.7 ±3.0	>70	217 ±199	72 ±12	-	>15[3]	225 ±11
Medium	(10)	0.9 ±0.3	5.4 ±0.8	2.57 ±0.31	5.9 ±1.1	>70	163 ±118	90 ±21	-	>15[3]	230 ±10
High	(9)	1.0 ±0.4	5.2 ±0.6	2.59 ±0.45	6.4 ±0.9	>70	118 ±54	88 ±22	-	>15[3]	244 ±13

(continued)

Table 68. (continued)

Age and Relative Dietary Cd	(n)	Mean ± S.D. for Serum[1] CRT	TP	ALB	P	AP	CPK	GPT	LDH	Ca	GLU
30 Weeks											
Low	(9)	0.7 ±0.3	4.9 ±0.5	1.97 ±0.28	6.4 ±2.5	>70	556 ±285	46 ±12	-	<15[3]	203 ±16
Medium	(9)	0.7 ±0.1	4.6 ±0.6	2.10 ±0.32	7.5 ±1.7	>70	555 ±196	43 ±10	-	>15	212 ±18
High	(9)	0.7 ±0.2	4.7 ±0.7	2.10 ±0.32	6.0 ±1.8	>70	501 ±231	51 ±14	-	<15[3]	214 ±16
H→L	(10)	1.0 ±0.2	4.8 ±0.9	1.96 ±0.24	6.6 ±2.0	>70	730 ±184	59 ±17	-	>15[3]	209 ±22
L→H	(10)	0.8 ±0.3	4.6 ±0.6	2.25 ±0.22	5.6 ±1.2	>70	599 ±195	52 ±23	-	<15[3]	203 ±23

1) CRT=Creatinine (mg/dl); TP=total protein (g/dl); ALB=albumen (g/dl); P=phosphate (mg/dl); AP=alkaline phosphatase; CPK=creatinine phosphokinase; GPT=glutamate-pyruvate transaminase; LDH=lactate dehydrogenase (all Hycel International units); Ca=calcium (mg/dl) and GLU=glucose (mg/dl).

2) Low and medium groups each had one excessively high glucose value (400) and some glucose values were quite low at 20 weeks. Group means excluding these values (deleted values in parentheses) were:

Low:	282 ± 68	(143, 68, 10)	252 ± 21 w/o 400
Medium:	276 ± 67	(52, 40)	251 ± 31 w/o 400
High:	252 ± 22	(56, 44, 14)	

3) Serum Ca was generally beyond the range of the method employed by 20 weeks. At 20 weeks, the "High group" had 3 values between 11-12, however. At 70 weeks, Low and Medium had 1 value each below 13 and High had 2 low values. At 80 weeks Low, L→H, and High had 2 low values each while H→L had one.

4) n=6

Table 69. Relative liver, gizzard, and kidney weights in white leghorn hens having received sludge-fertilized corn-soybean diets from one week of age.

Age and Relative Dietary Cd	(n)	Mean ± S.D. Weight as % Body		
		Liver[1)]	Gizzard[1)]	Kidney[1)]
8 Weeks				
Low	(16)	2.10 ± 0.21	2.11 ± 0.22	0.79 ± 0.08
Medium	(16)	2.18 ± 0.16	2.12 ± 0.18[2)]	0.84 ± 0.06
High	(16)	2.39 ± 0.26	2.30 ± 0.27	0.93 ± 0.17
20 Weeks				
Low	(12)	2.07 ± 0.88	1.30 ± 0.23	0.54 ± 0.06
Medium	(12)	2.25 ± 0.55	1.33 ± 0.16[2)]	0.53 ± 0.05
High	(12)	1.96 ± 0.47	1.59 ± 0.19[3)]	0.54 ± 0.06
30 Weeks				
Low	(4)	2.40 ± 0.29	1.13 ± 0.13	0.57 ± 0.04
Medium	(4)	2.34 ± 0.25	1.41 ± 0.15[3)]	0.65 ± 0.08
High	(4)	2.47 ± 0.51	1.42 ± 0.14[3)]	0.62 ± 0.03
50 Weeks				
Low	(16)	2.33 ± 0.59	1.16 ± 0.20	0.68 ± 0.13
Medium	(15)	2.74 ± 0.46	1.27 ± 0.15	0.66 ± 0.08
High	(16)	2.76 ± 0.30	1.33 ± 0.19[3)]	0.69 ± 0.06
70 Weeks				
Low	(10)	2.59 ± 0.64	1.21 ± 0.18	0.60 ± 0.06
Medium	(10)	2.62 ± 0.58	1.12 ± 0.16	0.64 ± 0.07
High	(10)	2.57 ± 0.61	1.20 ± 0.15	0.62 ± 0.07
L→H	(10)	2.80 ± 0.74	1.12 ± 0.13	0.58 ± 0.06
H→L	(10)	2.76 ± 0.31	1.11 ± 0.16	0.63 ± 0.08
80 Weeks				
Low	(10)	2.00 ± 0.34	1.21 ± 0.25	0.68 ± 0.08
Medium	(10)	2.30 ± 0.74	1.21 ± 0.16	0.70 ± 0.12
High	(10)	2.17 ± 0.60	1.20 ± 0.12	0.68 ± 0.11
L→H	(10)	1.98 ± 0.28	1.14 ± 0.16	0.69 ± 0.11
H→L	(10)	2.16 ± 0.49	1.12 ± 0.18	0.66 ± 0.08

(continued)

Table 69. (continued)

1) For collective data of 8, 20, and 30 weeks (n=32) the High Cd group was significantly different from the Low Cd and the Medium Cd was significantly different from the High Cd for all three tissues at $p < 0.01$. A single Low Cd bird had a very large liver and spleen at 20 weeks (4.68 and 0.35% body weight, respectively); excluding this bird, the mean relative liver weight for n=11 was 1.83 ± 0.33% and the mean relative spleen weight was 0.15 ± 0.03%.

2) Significantly different from High Cd group at $p > 0.01$.

3) Significantly different from Low Cd group at $p > 0.01$.

Table 70. Relative organ weights in white leghorn hens having received sludge-fertilized corn-soybean diets from one week of age.

Age and Relative Dietary Cd	(n)	Mean ± S.D. Weight as % Body				
		Heart	Brain	Proventriculus	Pancreas	Spleen
8 Weeks						
Low	(16)	0.45 ± 0.14	0.41 ± 0.03	0.44 ± 0.04	0.28 ± 0.03	0.20 ± 0.04
Medium	(16)	0.45 ± 0.04	0.43 ± 0.03	0.47 ± 0.12	0.34 ± 0.04	0.21 ± 0.04
High	(16)	0.43 ± 0.05	0.42 ± 0.03	0.45 ± 0.06	0.34 ± 0.04	0.22 ± 0.06
20 Weeks						
Low	(12)	0.34 ± 0.05	0.24 ± 0.03	0.26 ± 0.04	0.18 ± 0.03	0.17 ± 0.07[1)]
Medium	(12)	0.34 ± 0.05	0.22 ± 0.02	0.24 ± 0.03	0.18 ± 0.03	0.13 ± 0.02
High	(12)	0.38 ± 0.02	0.23 ± 0.03	0.26 ± 0.04	0.19 ± 0.03	0.16 ± 0.05
50 Weeks						
Low	(16)	0.38 ± 0.07	0.21 ± 0.02	-	0.20 ± 0.03	0.081 ± 0.014
Medium	(16)	0.42 ± 0.07	0.23 ± 0.02	-	0.24 ± 0.02	0.082 ± 0.019
High	(16)	0.43 ± 0.08	0.22 ± 0.03	-	0.25 ± 0.04	0.085 ± 0.019
70 Weeks						
Low	(10)	0.40 ± 0.07	0.23 ± 0.03	-	0.20 ± 0.02	0.087 ± 0.032
Medium	(10)	0.36 ± 0.04	0.22 ± 0.03	-	0.22 ± 0.03	0.083 ± 0.031
High	(10)	0.38 ± 0.05	0.22 ± 0.04	-	0.22 ± 0.03	0.081 ± 0.014
L-H	(10)	0.37 ± 0.08	0.22 ± 0.02	-	0.22 ± 0.05	0.082 ± 0.016
H-L	(10)	0.39 ± 0.06	0.21 ± 0.02	-	0.20 ± 0.02	0.075 ± 0.015
30 Weeks						
Low	(10)	0.39 ± 0.04	0.22 ± 0.03	-	0.19 ± 0.05	0.111 ± 0.051
Medium	(10)	0.40 ± 0.08	0.21 ± 0.03	-	0.20 ± 0.03	0.080 ± 0.024
High	(10)	0.39 ± 0.06	0.23 ± 0.02	-	0.23 ± 0.02	0.079 ± 0.018
L-H	(10)	0.36 ± 0.05	0.22 ± 0.03	-	0.21 ± 0.02	0.084 ± 0.014
H-L	(10)	0.39 ± 0.09	0.21 ± 0.03	-	0.19 ± 0.04	0.091 ± 0.024

1) For collective data of 8, 20, and 30 weeks (n=32) the High Cd group was significantly different from the Low Cd and the Medium Cd was significantly different from the High Cd for all three tissues at p <0.01. A single Low Cd bird had a very large liver and spleen at 20 weeks (4.68 and 0.35% body weight, respectively); excluding this bird, the mean relative liver weight for n=11 was 1.83 ± 0.33% and the mean relative spleen weight was 0.15 ± 0.03%.

Table 71. Fat content of livers from white leghorn hens having received sludge-fertilized corn-soybean diets from one week of age.

Age and Relative Dietary Cd	n	Liver Fat (mean ± S.D. % fresh weight)
8 Weeks		
Low	15	4.81 ± 0.75
Medium	13	4.38 ± 0.61
High	15	4.46 ± 0.96
20 Weeks		
Low	12	12.3 ± 6.0
Medium	12	21.6 ± 9.8
High	12	13.9 ± 8.4
30 Weeks		
Low	4	10.0 ± 3.7
Medium	4	9.3 ± 4.6
High	2	13.4 ± 4.9
50 Weeks		
Low	16	9.9 ± 4.1
Medium	16	12.0 ± 4.0
High	16	12.8 ± 5.9
70 Weeks		
Low	10	13.9 ± 6.5
Medium	10	18.1 ± 11.1
High	10	15.3 ± 6.6
H→L	10	15.8 ± 5.9
L→H	10	15.9 ± 7.3
80 Weeks		
Low	10	9.6 ± 6.9
Medium	9	11.0 ± 6.8
High	10	12.5 ± 8.6
H→L	10	8.1 ± 4.8
L→H	10	7.8 ± 4.2

Table 72. Hepatic microsomal parameters in white leghorn hens having received different levels of dietary Cd from one week of age.

Necr Time	Dose Group	Total Protein mg/g Liver	P-450 nm/mg Protein	NADPH nm/min/mg Protein
8 wk	Low	28.2 ± 6.9	.280 ± .084	.0316 ± .006
	Med	24.5 ± 3.2	.241 ± .119	.026 ± .006
	High	22.0 ± 5.9	.176 ± .057	.030 ± .008
20 wk	Low	10.65 ± 1.2	.159 ± .098	.025 ± .010
	Med	9.43 ± 1.3	.184 ± .059	.027 ± .008
	High	10.56 ± 2.2	.136 ± .018	.028 ± .004
30 wk	Low	12.55 ± 2.6	.112 ± .075	.026 ± .001
	Med	12.43 ± 2.4	.119 ± .051	.027 ± .003
	High	11.97 ± 2.0	.122 ± .039	.029 ± .008
50 wk	Low	15.86 ± 2.7	.243 ± .019	.023 ± .007
	Med	17.13 ± 1.4	.181 ± .089	.020 ± .009
	High	15.99 ± 2.2	.219 ± .079	.024 ± .006
70 wk	Low	17.73 ± 2.5	.233 ± .16	.030 ± .008
	Low→High	14.39 ± 2.9	.252 ± .17	.039 ± .005
	Med	17.04 ± 2.6	.186 ± .08	.034 ± .005
	High→Low	15.62 ± 2.7	.209 ± .13	.037 ± .009
	High	15.42 ± 2.4	.191 ± .12	.038 ± .006
80 wk	Low	15.60 ± 2.9	.200 ± .09	.028 ± .010
	Med	16.51 ± 1.86	.140 ± .056	.022 ± .008
	High	16.85 ± 2.4	.135 ± .071	.029 ± .006

Table 73. Hepatic microsomal O-dealkylation of p-nitrophenetole in white leghorn hens having received dietary Cd from one week of age.

Age and Relative Dietary Cd	n	n moles/minute/mg protein 0.05 mM	2.0 mM
8 Weeks			
Low	5	1.55 ± 0.43	4.45 ± 1.03
Medium	4	1.52 ± 0.37	4.08 ± 1.08
High	4	1.70 ± 0.21	4.75 ± 0.38
20 Weeks			
Low	5	1.57 ± 0.55	3.32 ± 0.67
Medium	5	1.42 ± 0.63	2.90 ± 0.26
High	8	1.61 ± 0.30	3.15 ± 1.06
50 Weeks			
Low	7	0.85 ± 0.19	2.10 ± 0.55
Medium	9	0.90 ± 0.20	1.96 ± 0.52
High	8	1.06 ± 0.26	2.35 ± 0.46
70 Weeks			
Low	5	1.09 ± 0.26	-
Medium	6	1.16 ± 0.25	2.61 ± 0.32
High	6	1.18 ± 0.12	2.71 ± 0.40
80 Weeks			
Low	6	1.22 ± 0.33	2.56 ± 0.58
Medium	6	1.02 ± 0.25	2.21 ± 0.33
High	6	1.18 ± 0.32	2.61 ± 1.00

SECTION 6

ABSTRACT OF THESIS RESEARCH

CADMIUM-INDUCED GROWTH DEPRESSION AND CADMIUM ACCUMULATION IN CHICKS AS INFLUENCED BY DIETARY MODIFICATIONS

Nine experiments were conducted with week-old crossbred meat-type chicks to explore the effect of dietary nutrient balance upon the response of chicks to cadmium. When 1, 5, 10, 15, 20, 30, and 40 ppm of Cd as Cd/Cl_2 was added to corn-soya diets for two weeks, there was growth depression at 10 ppm and a dose-related increase in the Cd content of kidneys and livers due to added Cd. As the Cd intake was increased, there was an increase in the percent of ingested Cd retained in these two tissues.

Simultaneous decreases in dietary Ca, 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 increased Cd retention. Supplemental Zn and levels of Ca 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 of 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 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.

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