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Physical-Chemical Characteristics and Heavy Metal Content of Corn Grown on Sludge-Treated Strip-Mine Soil

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Corn was grown on strip-mine soil where anaerobically digested liquid sludge had been applied at a rate of 25 tons of sludge solids per acre. An adjacent plot of soil received no sludge. Corn grain grown on untreated strip-mine soil was characterized as immature and kernel size varied from small to intermediate, with about 20% of the kernels being diseased. In contrast, sludge-grown corn was well developed and corn yield increased fourfold over the untreated corn. Furthermore, a significant protein enhancement of 2.5 percentage points was also realized. Concentrations of seven heavy metals (Zn, Mn, Cu, Pb, Cr, Cd, Hg) increased in grain, cobs, and husks in that order. For corn grain grown on untreated and sludge-treated soils, essentially no significant differences were found in heavy metal content when compared to 11 other corn varieties grown normally. Heavy metal contents of both soil and sludge samples were also determined.

A preliminary investigation was initiated to study corn grown under unique conditions—on strip-mine land treated with anaerobically digested liquid sludge. The Metropolitan Sanitary District of Greater Chicago has instituted a project in Fulton County in Central Illinois encompassing two major objectives: (a) disposing of anaerobically digested sludge and (b) upgrading organically deficient strip mine soil to the point where it can be productive agriculturally. Corn, a product of major commerical importance in this area, was chosen as the demonstration crop to study the effects of land application of sludge under specific controlled conditions.

A commerical yellow seed corn was planted in a tilled field of strip-mine soil. For comparative purposes, one plot was treated with sludge representing an equivalent of 25 tons of solids per acre, and an adjacent plot was not treated with sludge. On October 28, 1971, corn samples representing sludge-treated and untreated conditions were collected.

We measured the major physical and chemical characteristics of the whole kernel corn produced and grown under these two conditions. In addition, we determined the heavy metal content for parts of the corn plant that were contiguous with the whole kernel to establish the uptake of these metals. We wanted to answer the important question—are heavy metals, which are present in the sludge in very small quantities, translocated by way of the soil to the various parts of the corn plant, particularly the edible parts? The metals studied included zinc, manganese, copper, lead, chromium, cadmium, and mercury.

Previously, Braids *et al.* (1970) studied the effect on crop yields of Reed Canary grass and sorghum grain but where digested sludge was applied to lysimeters. They also determined the elemental uptake of manganese, iron, copper, and zinc by corn grain and leaves.

MATERIALS AND METHODS

Sample Collection and Preparation. In each plot (untreated and sludge-treated), corn ears with husks intact were removed from the plants in the field and placed in large plastic-lined paper bags. Each bag contained ears representing many plants, and several bags were filled from each plot. The sealed bags were placed in cold storage at −29° until the samples were to be examined.

For analytical work, a composite whole grain corn sample representing each plot was prepared. For representative corn ear selection, all the bags were removed from cold storage and the contents were allowed to come to ambient laboratory temperature. All the ears of corn were separated into three relative sizes: large, medium, and small. An equal number of ears of each of the three sizes was then taken to start the formation of the composite grain sample. To avoid cross-contamination between untreated and sludge-treated samples, work on each lot was done on separate days.

The husks were removed and collectively gathered in a large plastic bag. The ears with the kernels intact were weighed and recorded. The kernels from each ear were then removed by hand and counted and both kernels and cob were weighed separately. To form a composite grain sample, all the kernels from each succeeding ear of corn were combined cumulatively until the total exceeded 10,000 kernels. The resultant composite samples required

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Table I. Flame Atomic Absorption Operating Conditions and Instrumental Parameters for Corn Component Analysis

Element	Resonance line, λÅ	Hollow cathode lamp current, MA	Concn range of aq solution, μg/ml	Scale expansion	Sensitivity attained[a]
Zinc	2137	6	0.20–2.50	1X	0.0185
Lead	2170	6	0.10–1.50	15X	0.0173
Cadmium	2286	3	0.02–0.50	14X	0.0027
Manganese	2794	5	0.20–1.00	6X	0.0097
Copper	3249	3	0.10–1.25	8X	0.0113
Chromium	3577	5	0.05–1.20	15X	0.0130

[a] Micrograms/milliliter per 1% absorption.

56 ears (10,590 kernels) and 20 ears (10,650 kernels) of untreated and sludge-grown corn with total kernel weights of 2336 and 3244 g, respectively. The cobs were collectively gathered and stored in a large plastic bag. Data for each ear were recorded for statistical evaluation of the physical characteristics. The kernels from each composite sample were placed on large plastic sheets and allowed to air dry for at least 24 hr; then the sample was thoroughly mixed to get homogenous sample representation. Glass jars, previously cleaned with nitric acid, were used to store the composite samples in a refrigerator.

Also collected were entire corn plants with the soil adhering to the root system. Each plant with adhering soil was transferred to a large plastic bag, sealed, and placed in cold storage at −29°. Now being determined are the heavy metal contents involving the whole corn plant and soil associated with its root system.

Three soil samples were collected in 8-oz plastic bottles from each area of the cornfield representing untreated and sludge-treated plots. The two sets of three were collected in a triangular conformation at distances of about 50 ft apart and to a depth of about 6 in.

On October 28, 1971, sludge samples were collected at the Fulton County site in 1-gal plastic bottles. Samples were obtained from the exit side of the 20-in. pipeline before the sludge, which was flowing at a high velocity, entered a lagoon.

Analytical Techniques and Procedures. Protein and fiber content of the corn were measured by standard methods (AACC, 1962). Fat content was determined by extracting the ground corn sample with hexane in a Soxhlet extraction apparatus for 17 hr. Ash was determined by ignition in a platinum dish at 575° for at least 16 hr. Starch was measured by a polarimetric method with 90% dimethyl sulfoxide as the starch solvent (Garcia and Wolf, 1972).

Six heavy metals were determined by flame atomic absorption techniques using a Varian Techtron AA-120 atomic absorption spectrophotometer with an external recorder. Scale-expansion techniques were employed as needed (Table I). Absorption data were acquired by aspirating for about 1 min either aqueous standard solutions or wet-ashed sample solutions similar in acid concentration (Garcia *et al.*, 1972).

For mercury determination of the corn components, approximately 10 g of either kernels, cobs, or husks was decomposed with concentrated HNO_3 at 70°. To the cooled beaker was added concentrated HCl to form an aqua regia mixture, and heating was continued to ensure complete solubilization of the mercury. The mercury salts were retained in a diluted aqua regia solution similar to the method of Lee and Laufmann (1971). The mercury was then reduced chemically to its elemental form before it was deemanated so that the vapor could be measured by a nonflame technique in a Coleman MAS-50 mercury analyzer. Absorption data were recorded on a Beckman 10-in. recorder.

Similarly treated soil and sludge samples, but without the removal of silica with HF, required sample sizes of approximately 2.5 g and 20 ml, respectively, for mercury analyses.

Decomposition and Wet Ashing for Flame Atomic Absorption. *Corn Samples.* To 10 g of whole grain in a 250-ml Phillips beaker was added 40 ml of redistilled, concentrated HNO_3. With a glass cover on the beaker, the initial decomposition was allowed to proceed at room temperature for 2 hr. After the beaker was placed on a hot plate, an exothermic reaction occurred and was characterized by copious fumes of oxides of nitrogen. After the vigorous reaction subsided, heat was adjusted to a temperature that would maintain concentrated HNO_3 (a reagent blank) at about 70°. After 3 hr, 2 ml of 70% $HClO_4$ was added and heating was continued until a clear solution appeared. Eventually fumes of $HClO_4$ appeared after the removal of HNO_3. When the ashing process was completed, $HClO_4$ was removed by evaporation. The salts were converted to chlorides by successively treating the residue with concentrated HCl and double distilled water. Finally, 1 ml of concentrated HCl was added to the residue. The mixture was warmed before 15 ml of double-distilled water was added; the diluted solution was warmed for 30 min. The solution was then diluted to 25 ml with water. This final solution represented the equivalent of 1 g of original corn sample per 2.5 ml of a 4% HCl solution.

The wet ashing of both the cob and husk samples proceeded in an identical manner as that described for whole grain, except that after the removal of $HClO_4$ by evaporation, the residue was dissolved in dilute HCl and transferred quantitatively to a 100-ml Teflon beaker to which was added 5 ml of 48% HF. This mixture was evaporated to dryness at steam bath temperature in the hood. The residue was again treated with HCl and HF and again evaporated to dryness. To remove traces of HF, the residue was treated with HCl and water and then evaporated. Finally, 1 ml of concentrated HCl was added, the solution was warmed, and then 15 ml of double-distilled water was added, warmed for 30 min, and diluted up to 25 ml as previously described.

Both cobs and husks had to be treated with HF to remove silica in them after the sample had been ashed. If silica is not removed, metal adsorption might occur; also any imperceptible particles obstruct the flow of a solution through the atomic absorption aspiration system. Blanks were carried through the procedures with each type of sample.

Soil Samples. Dried soil samples were broken up with a mortar and pestle, mixed thoroughly, and quartered. One-quarter (*ca.* 60 g) was ground with a mortar and pestle to a fine powder, mixed, and rolled thoroughly on a plastic sheet. Approximately 3 g of sample was then weighed into a 250-ml Teflon beaker, and 20 ml of concentrated HNO_3 was added. This mixture was digested in the covered beaker on a hot plate. To remove silica, 10 ml of 48% HF was added to the cooled beaker, and the mixture was evaporated to dryness at steam bath temperature in a hood. This same treatment with HNO_3 and HF was repeated

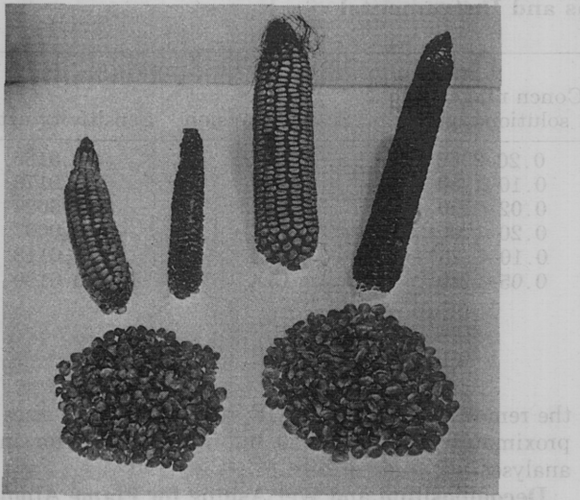

Figure 1. Corn—ears, cobs, and grain (composite samples). Samples of corn grown on untreated strip-mine soil, left; samples of corn grown on strip-mine soil treated with sludge, right.

twice. Traces of HF were removed by evaporating the residue to dryness several times with 3 ml of concentrated HNO_3 and 15 ml of double-distilled water.

To commence wet ashing, 40 ml of concentrated HNO_3 was added to the residue. The sample in the glass-covered beaker was allowed to digest on the hot plate at 70° for several days to ash the organic matter effectively. When the ashing was almost completed the solution was evaporated to dryness, and the residue was treated with concentrated HCl and double-distilled water several times to convert the salts to chlorides. The residue was finally dissolved in 50 ml of 10% HCl, heated for 30 min, cooled, and filtered through filter paper. The filtrate was retained; the residue and filter paper were transferred back to the Teflon beaker for wet ashing with concentrated HNO_3 for about 1 day.

After conversion to chlorides, the salts were dissolved in 10% HCl medium and filtered through paper again. This procedure of wet ashing and subsequent filtration of the solution in 10% HCl was repeated twice, the end result being that the total 3 g of sample was eventually dissolved in a total volume of 250 ml of approximately 10% HCl medium. The solution was transferred to a polyethylene storage bottle for subsequent measurement of metals by atomic absorption. Where further dilutions were required, this solution was diluted approximately eight times.

Sludge Samples. The bottles of sludge, collected at the site, were shaken immediately before duplicate 100-ml samples (density 0.998, 2.5% solids) were transferred to Teflon beakers. To each beaker was added 20 ml of concentrated HNO_3 followed by 10 ml of 48% HF, and this mixture was evaporated to dryness as previously described for the soils. Treatment with HF was again repeated. After removal of traces of HF, 40 ml of concentrated HNO_3 was added, and wet ashing was accomplished by digestion on the hot plate at 70° for several days.

Successive conversion of the ashed salts to chlorides and solubilization of the salts in approximately 10% HCl medium were carried out as previously described. The residue remaining on the filter paper required only one additional ashing treatment before complete solubilization occurred. The combined filtrates were diluted to give a total volume of 200 ml. This step produced duplicate solutions, each representing 100 ml of original sludge in a 200-ml 10% HCl medium.

RESULTS AND DISCUSSION

Physical-Chemical Characteristics of Corn Grain. Kernels from the composite corn sample grown on untreated strip-mine soil appeared immature and reflected stress conditions. There was considerable variation in kernel size, ranging from small to intermediate, with no characteristic indentation on the kernels. Smaller reddish-brown kernels were also present, and about 20% of the total kernels were diseased. In contrast, kernels from the composite representing sludge-grown corn were well developed with minor variation in size. Typical yellow kernels approached the normal dent appearance of commerical-grade corn, but some kernels did not show any indentation. No diseased kernels were present. Shown in Figure 1 are kernels from both composite corn samples with typical corncobs and ears appearing in the background.

Yield data showed that weights of the ears of corn and weights of kernels derived from individual ears were almost four times greater for the sludge-grown than for the untreated corn (Table II). Additionally, cob weights and number of kernels per individual ear were almost three times greater for the sludge-grown corn. The possible effects on growth, as a result of the additional quantity of water supplied by the sludge application, were not determined.

In a consecutive 3-year study by the Metropolitan Sanitary District of Greater Chicago on soybean yields (Hinesly, 1972), increments of sludge were applied on Blount silt loam at different application rates with depths of total liquid sludge ranging from 8 to 13 in. To study parallel effects quantities of well water were added to the soil equivalent to the amount available at the maximum sludge application rate. In 2 of the 3 years, soybean yield increases reflected the water-only treatment; however, these two yield increases were less than those gained with sludge application.

Sludge enhanced corn kernel yield on an individual ear basis, depicted graphically in Figure 2. In addition, larger kernels developed (Figure 3).

To acquire representative corn grain samples containing more than 10,000 kernels to be used for subsequent chemical and heavy metal analyses required 56 ears of untreated corn and 20 ears of sludge-treated corn. Thorough mixing when compositing corn grain samples was essential, and the aim was to maintain similar numbers of kernels in the composited samples.

The effect of sludge application on the composition of the corn grain is readily seen in Table III. Protein, fat, and fiber values were lower for the untreated corn and may have reflected its immature characteristics although

Table II. Mean Values for Physical Characteristics of Ear Corn

Physical characteristic	Untreated corn (56 ears, 10,590 kernels)	Sludge-grown corn (20 ears, 10,650 kernels)	Sludge: untreated
Wt cob + kernels, g	53.5 (12.3–144.5)[a]	200.3 (91.1–360.3)	3.7
Wt cob, g	11.9 (2.6–63.0)	34.3 (17.9–81.3)	2.9
Wt kernels per ear, g	41.7 (6.7–99.5)	162.2 (73.0–275.5)	3.9
No. kernels per ear	189.1 (42–358)	532.5 (333–662)	2.8
Wt per 100 kernels, g	21.5 (12.1–36.3)	29.8 (21.2–43.4)	1.4

[a] Range of values in parentheses.

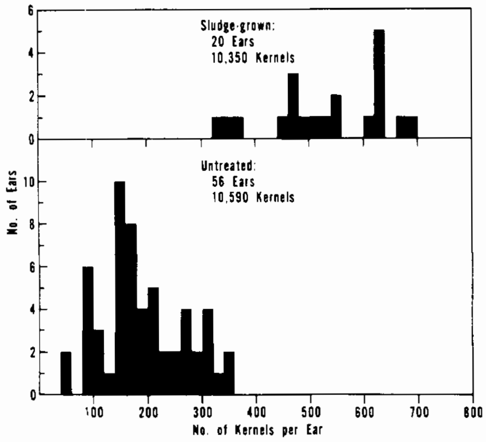

Figure 2. Variation in kernel yield per ear of corn grown on sludge-treated and untreated strip-mine soil.

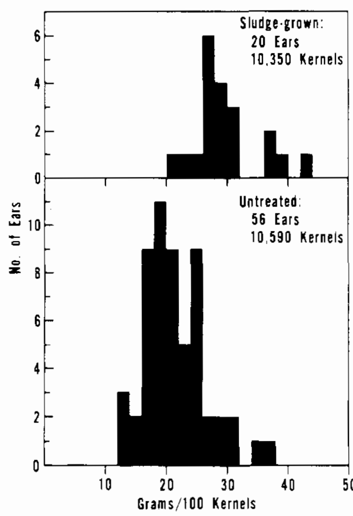

Figure 3. Variation in kernel weight.

the starch content (77.0%) was somewhat higher than usually encountered. The ash content and the amylose content of the starch (29.0%) were the same for both untreated and sludge-grown corn. A significant difference of 2.5 percentage points in protein content demonstrated that sludge definitely improved nutritional quality of the corn. Additionally, fat and fiber contents also showed that the sludge-treated corn developed and matured considerably better. Similarity in ash content probably indicated no appreciable difference in mineral composition.

Uptake and Distribution of Heavy Metals. The uptake and distribution of heavy metals in the corn plant were of foremost concern, and our primary objectives in this initial approach were to examine the kernels and those parts of the corn plant that were contiguous with the kernels. Because of the importance of corn grain in human and animal diet, special emphasis was placed on this specific part of the corn plant. For statistical signifi-

Table III. Composition of Untreated and Sludge-Grown Corn[a]

Composite corn sample from strip-mine soil	Protein, %	Starch, %	Fat, %	Ash, %	Fiber, %
Untreated	9.2	77.0	3.3	1.4	1.5
Sludge-grown	11.7	73.4	3.8	1.4	2.6

[a] Reported values represent mean of two values, except mean of four values for protein (moisture-free basis).

Table IV. Comparison of Heavy Metal Concentration Values (ppm, Dry Basis) for Composite Whole Kernel Corn Samples

Sample designation	Zinc	Manganese	Copper	Lead	Chromium	Cadmium	Mercury
Corn grown on strip-mine soil							
Untreated, A	35.2	5.17	2.77	0.384	0.039	0.033	0.0003
B	33.9	4.80	2.53	0.284	0.036	0.029	0.0003
C	32.8	4.86	2.48	0.361	0.034	0.032	0.0003
D	32.8	5.20	2.60	0.309	0.040	0.036	0.0003
E	31.9	5.17	2.33	0.307	0.038	0.035	0.0000
F	35.6	5.59	2.61	0.383	0.034	0.032	0.0003
Mean	33.7 ±	5.13 ±	2.55 ±	0.338 ±	0.037 ±	0.033 ±	0.00025 ±
Std dev	1.5	0.28	0.15	0.043	0.003	0.002	0.00005
Sludge-grown, G	26.9	4.72	2.75	0.259	0.044	0.077	0.0010
H	26.5	4.68	2.57	0.286	0.040	0.055	0.0009
I	26.2	5.18	2.31	0.246	0.045	0.050	0.0010
J	27.9	5.13	2.38	0.287	0.052	0.101	0.0003
K	26.8	5.09	2.43	0.271	0.040	0.050	0.0005
Mean	26.9 ±	4.96 ±	2.49 ±	0.270 ±	0.044 ±	0.067 ±	0.00074 ±
Std dev	0.6	0.24	0.17	0.018	0.005	0.023	0.00032
Group I,[a] mean	23.0 ±	6.45 ±	1.88 ±	0.274 ±	0.073 ±	0.065 ±	0.0030 ±
Std dev	2.9 (18.7–27.2)[c]	1.40 (4.52–7.66)	0.09 (1.74–1.99)	0.048 (0.198–0.340)	0.043 (0.025–0.155)	0.042 (0.035–0.148)	0.0017 (0.0018–0.0062)
Group II,[b] mean	22.7 ±	6.79 ±	2.31 ±	0.267 ±	0.044 ±	0.042 ±	0.0018 ±
Std dev	1.2 (20.9–23.8)	0.70 (5.86–7.78)	0.61 (1.65–3.10)	0.029 (0.231–0.302)	0.013 (0.033–0.066)	0.004 (0.036–0.048)	0.0017 (0.0005–0.0041)

[a] Mean and standard deviation of six different corn samples representing a geographical growth area covering six states. [b] Another group of five different corn varieties. [c] Range of values in parentheses.

Table V. Comparison of Heavy Metal Concentration Values (ppm, Dry Basis) for Corncobs Representing Individual Ears

Sample Designation	Zinc	Manganese	Copper	Lead	Chromium	Cadmium	Mercury
Cobs							
Untreated							
No. 1	70.6	9.21	3.86	0.581	0.173	0.072	0.0089
No. 2	76.1	7.16	2.10	0.343	0.346	0.113	0.0066
No. 3	50.6	9.62	4.45	0.665	0.264	0.072	0.0067
No. 4	94.5	4.47	2.46	0.540	0.194	0.080	0.0075
No. 5	97.7	13.42	6.85	0.929	0.205	0.081	0.0053
Mean	77.9	8.78	3.94	0.612	0.236	0.084	0.0070
Sludge-grown							
No. 6	15.9	9.41	4.18	0.232	0.274	0.157	0.0095
No. 7	15.7	6.24	3.25	0.268	0.261	0.108	0.0091
No. 8	29.3	7.48	2.43	0.153	0.173	0.101	0.0081
No. 9	28.4	12.08	5.25	0.375	0.257	0.119	0.0153
No. 10	13.7	10.58	4.43	0.299	0.258	0.084	0.0175
Mean	20.6	9.16	3.91	0.265	0.245	0.114	0.0119

Table VI. Comparison of Heavy Metal Concentration Values (ppm, Dry Basis) for Corn Husks Representing Individual Ears

Sample designation	Zinc	Manganese	Copper	Lead	Chromium	Cadmium	Mercury
Husks							
Untreated							
No. 1	62.6	21.1	5.07	1.44	0.762	0.132	0.0078
No. 2	62.3	30.1	6.45	2.69	0.868	0.205	0.0237
No. 3	61.6	22.5	4.49	2.13	0.635	0.139	0.0182
No. 4	82.1	23.2	5.27	2.50	0.538	0.151	0.0144
No. 5	74.7	23.9	4.46	2.04	0.554	0.154	0.0145
Mean	68.7	24.2	5.15	2.40	0.671	0.156	0.0157
Sludge-grown							
No. 6	12.4	13.8	4.58	1.15	0.379	0.230	0.0276
No. 7	9.1	15.7	4.22	1.77	0.305	0.126	0.0241
No. 8	15.6	20.9	4.47	1.57	0.321	0.215	0.0138
No. 9	21.0	23.3	4.71	1.09	0.241	0.161	0.0228
No. 10	32.7	19.0	6.20	0.56	0.266	0.171	0.0236
Mean	18.2	18.5	4.84	1.23	0.302	0.181	0.0224

Table VII. Heavy Metal Content (ppm) of Strip-Mine Soils

Sample designation	Zinc	Manganese	Copper	Lead	Chromium	Cadmium	Mercury
Soil							
Untreated							
No. 1	125	859	35.4	30.4	78.4	1.87	0.072
No. 2	125	643	33.2	27.1	78.0	1.92	0.055
No. 3	90	774	36.6	28.5	87.3	1.68	0.045
Mean	113	759	35.1	28.7	81.2	1.82	0.057
Sludge-treated							
No. 4	1318	929	438	271	683	71.9	0.731
No. 5	721	587	228	156	383	37.2	0.472
No. 6	1281	799	417	278	655	69.8	0.820
Mean	1107	772	361	235	574	59.6	0.641

cance, replicate 10-g whole-kernel samples were withdrawn from the composite sample container, and they were analyzed for seven metals. The metal concentrations derived therefrom were then related to metal concentrations as previously determined in 11 different corn varieties (six of known geographical origin) grown under normal soil conditions (Table IV).

Because cobs and husks are adjacent to the kernel, the relative abundance of the seven metals in these two components is important. Metal concentrations were measured in cobs and husks representing individual ears of corn.

Zinc and lead were higher in the untreated corn grain than in corn grown on sludge-treated strip-mine soil. The significantly higher zinc values could possibly be due to the effect of growth under stress conditions. In contrast, sludge-grown corn showed higher values for both cadmium and mercury. The difference in mean lead concentrations between untreated and sludge-grown corn was minor, especially when individual values are compared to concentration ranges found in the 11 corn varieties previously analyzed. Although the mean cadmium concentration value for sludge-grown corn was double that of untreated corn, all individual values listed were within the range determined in group I samples. It should also be emphasized that values for mercury were extremely low, and as such they occurred near the detection limit (slightly less than 0.001 ppm) for that analysis. Thus no real difference in mercury concentrations could be ascribed between untreated and sludge-grown corn. In addition mercury values for both untreated and sludge-grown corn were lower than previously established concentrations for the 11 corn samples. From this comparison with 11 other corn varieties, it was concluded that no real differences existed in heavy metal concentration between the different corns with the exception of the zinc content in the untreated corn.

Heavy metal concentrations for corncobs and husks are shown in Tables V and VI. For the corn components, the

Table VIII. Heavy Metal Content of Sludge Sample[a]

	μg/ml						
Sample designation	Zinc	Manganese	Copper	Lead	Chromium	Cadmium	Mercury
Sludge							
1	123	4.50	34.9	27.9	93.0	7.67	0.075
2	133	4.48	40.6	28.3	98.7	7.79	0.075
3							0.079
4							0.085
5							0.081
Mean	128	4.49	37.8	28.1	95.9	7.73	0.079

[a] Collected on October 28, 1971, with density of 0.998 and 2.5% total solids.

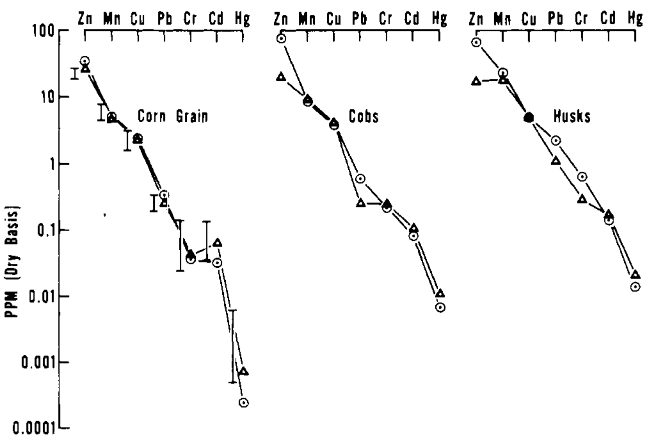

Figure 4. Comparison of heavy metal concentrations: (⊙) untreated; (Δ) sludge grown; (⊢—⊣) concentration ranges of 11 other corn varieties.

increasing order of heavy metal concentration was grain, cobs, and husks for all metals except zinc. Zinc concentrations in the untreated cobs and husks were more than three times higher than their sludge-grown counterparts, a similar observation previously noted in the grain. Apparently organically deficient strip-mine soil caused the corn plant to concentrate zinc in the cob and husk and to a lesser degree in the kernel. Zinc values for the sludge-grown corn plant were all generally in the same range (18.2–26.9 ppm).

For comparative purposes, the mean heavy metal concentrations for corn grain, cobs, and husks representing both untreated and sludge-grown conditions are graphically represented in Figure 4. Adjacent to these plotted concentration values for the grain are range concentrations for the 11 corn varieties.

Heavy Metal Content of Soil and Sludge. To study effectively the uptake of heavy metals by the corn plant, data on heavy metal concentrations in the soil were needed. Although we focused primarily on the heavy metal content in the corn plant, we did establish the presence and quantity of heavy metals in the soil. Our investigation did not deal with soil–plant interactions, such as heavy metal complexing by soil constituents, or with the availability of the metals to the plant. Table VII shows the metal content of three soil samples randomly collected that represent untreated strip-mine soil and the sludge-treated soil. Only for manganese did the sludge-treated soil show no appreciable increase. The initial content of manganese in the strip-mine soil was high (759 ppm), whereas the contents of cadmium (1.82 ppm) and mercury (0.057 ppm) were low.

A sludge sample was collected just before it entered the lagoon on the day the crop and soil samples were taken from the field. It should be noted that the sludge applied to the soil was not the same sludge sampled here. The heavy metal analysis as reported in Table VIII reflects information for that day only and indicates the magnitude of these metals when the density and total solids content are considered.

SUMMARY

Growing corn of good quality on strip-mine soil is almost impossible. Yield (13 bu/acre) and quality are so poor that the grain has little or no commerical value. Application of sludge to this same soil increased yield about four times and corroborated field yield values. Nutritional quality and kernel size are judged to be essentially equivalent to commerical-grade corn.

Along with the beneficial fertilizer and mineral components present in the sludge are heavy metal elements in the parts per million range. No significant increase in concentration of seven heavy metals occurred in corn grown on either untreated or sludge-treated strip-mine soil when compared with 11 varieties grown normally. Heavy metal concentrations varied among the three contiguous corn parts studied for both untreated and sludge-grown plants. Generally, an increasing order of concentration of metals was corn grain, cobs, and husks.

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