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Multielement Absorption by Crops Grown on Soils Amended with Municipal Sludge Ashes

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Beans, cabbage, carrots, millet, onions, potatoes, and tomatoes were grown in pots containing soils amended 5% by weight with municipal sludge ashes from Indianapolis, Indiana, or Kalamazoo, Michigan. Forty-two elements were determined in the edible plant tissues and growth media by neutron activation, furnace atomic absorption, anodic stripping voltammetry, and other methods. Boron, molybdenum, and selenium increased most consistently in the crops as a result of the sludge ash amendments. The plants did not exhibit symptoms of phytotoxicity.

About 5 million metric tons of sewage sludge is produced annually in the United States presently (Cahill, 1976). It is presently disposed by ocean dumping, discarding in landfills, incineration, and to a minor extent as a soil amendment on lawns, ornamentals, forests, and agricultural land. Municipal sludge may contain elevated concentrations of Cd, Ni, Zn, Cu, Cr, and other elements resulting largely from industrial wastes. Much research is therefore underway to determine the extent of absorption of toxic elements by edible crops (Furr et al., 1976a) and this subject has been reviewed by Cahill (1976) and Page (1974).

When municipal sewage sludge is disposed of by incineration, the remaining ash may constitute from 30 to 60% of the original sludge burned on a dry weight basis (Furr et al., 1976b). This residue therefore still comprises a sizable disposal problem. Investigations of the possible use of municipal sludge ash as a soil fertilizer amendment have not been published. Since many nutrient and toxic elements might expectedly remain in sludge ash, the present study was conducted to learn the possible extent of absorption of a range of such elements by a variety of crops grown in the greenhouse in potted soils amended with sludge ash.

EXPERIMENTAL PROCEDURES

Sludge ashes from the cities of Indianapolis, Indiana, and Kalamazoo, Michigan, were used. Table I lists data pertaining to the sources, treatment, and handling of these sludges during the production of ash. The Indianapolis and Kalamazoo ashes had fertilizer equivalents, respectively, of 0.1–11.9–1.5% and 0.06–8.7–5.7% $N-P_2O_5-K_2O$. The ashes were air-dried, pulverized in a hammermill through a 3-mm screen, and mixed by tumbling.

The soils used were a Darien gravelly silt loam (fine-loamy, mixed, mesic aeric ochraqualfs) and a Teel silt loam (coarse-silty, mixed, mesic fluvaquentic entrochrepts). Table II gives data concerning the ashes and soils used to prepare the potting mixtures. The soils, sampled near Ithaca, New York, were air-dried, sifted through a 2-mm screen, and mixed by quartering. The ash was mixed with the respective soil (Table II) using a cement mixer. The rate of ash addition was equivalent to 111.2 metric tons/h (50 tons/acre).

The crops used were "Long Tendergreen" bush bean (*Phaseolus vulgaris*), "Golden Acre" cabbage (*Brassica oleracea* var. *capitata*), "Scarlet Nantes" carrot (*Daucus carota* var. *sativa*), Japanese millet (*Echinochloa crusgalli* var. *frumentacea*), "1620 Pedro" onion (*Allium cepa*), "Katahdin" potato (*Solanum tuberosum*), and "New Yorker" tomato (*Lycopersicon esculentum*). All of the crops were grown in 7.6-L plastic pots except potatoes which were grown in 11.4-L pots. The weights of growth media contained in the 7.6- and 11.4-L pots were, respectively, 6 and 10 kg for Indianapolis-Darien ash–soil mixture and 8 and 13 kg for Kalamazoo-Teel mixture. Equal weights of the particular soil alone was used for growth of the control crops. The number of plants grown in each pot were: bean, 3; cabbage, 1; carrot, 10; millet, 5; onion, 10; potato, 1; and tomato, 1. All treatments were replicated four times. All plants were fertilized weekly with 1000 mL (1500 mL for the 11.4-L pots) of a solution containing reagent grade KH_2PO_4 (0.001 M) and KNO_3 (0.005 M) (Hoagland and Arnon, 1950). All plants were watered daily, care being taken to avoid splashing soil on the aerial portions of the plants.

At maturity the crops were harvested. Only the edible portions were collected for analysis. Prior to analysis all crop portions were rinsed with distilled water to remove adhering dust. Carrots, onions, and potatoes were brushed, rinsed, and peeled. The respective, replicated, edible plant portions were combined and subdivided by homogenizing

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Table I. Data Pertaining to the Composition, Treatment, and Handling of the Sludges Used during Ash Production

city	sewage treatment plant	ratio (%) industrial/ domestic contribution	dewatering scheme	combustion unit	combustion temp, °C	feed rate ton/h[a]	additives	ultimate ash disposal method
Indianapolis, IN	Dept. Public Works	70:30	vacuum filtration	Multiple (8) hearth	800-1000	5	none	landfill
Kalamazoo, MI	City of Kalamazoo Treatment Plant	50:50	vacuum filtration	Multiple (7) hearth	775	7	none	landfill

[a] Moist sludge cake.

Table II. Data Concerning the Sludge Ash-Soil Potting Mixtures Used

soil	soil pH	soil exchange capacity, mequiv/100 g	sludge ash	sludge ash pH	% (dry wt) ash in soil	ash-soil mixture pH
Darien gravelly silt loam	5.5	20.8	Indianapolis	8.2	5	7.3
Teel silt loam	6.8	13.9	Kalamazoo	6.9	5	7.0

in a blender or chopping in a food cutter with stainless steel surfaces. The plant material was freeze-dried in polystyrene containers, mixed, and subsampled for analysis. Samples of the soils and sludge ashes were also taken for analysis.

The soil, ash, and crop samples were analyzed for 35 elements using nondestructive neutron activation analysis as previously described (Furr et al., 1976). In addition, several elements were determined by other methods. Boron was analyzed by the curcumin colorimetric procedure (Greweling, 1966). Cadmium, lead, and zinc were determined by convertional stripping voltammetry (Gajan and Larry, 1972). Mercury was measured by flameless atomic absorption analysis (Hatch and Ott, 1968). Nickel was analyzed by the furnace atomic absorption method. Phosphorus was determined by the molybdivanadophosphoric acid spectrophotometric procedure (Kitson and Mellon, 1944). Selenium was measured by the fluorometric method of Olson (1969). Nitrogen was assayed by the Kjeldahl method. The determination of pH was done by the procedure of Peech et al. (1953).

RESULTS AND DISCUSSION

Table III gives the total elemental concentrations as determined in the soils and sludge ashes. Of the 42 elements analyzed, 28 were higher in the sludge ashes than in either soil. The higher concentrations of elements such as cadmium, copper, nickel, lead, and zinc in the Indianapolis sludge ash probably reflects the higher percentage of industrial contributors (Table I). The elemental composition of sludge ashes may vary considerably depending on the composition of the wastewater and operating conditions during incineration. Volatile elements such as halogens, mercury, and selenium would expectedly undergo some loss during the combustion process. Selenium, however, does concentrate in the fly ash during coal combustion (Furr et al., 1977) and apparently also concentrates in the ash during sludge incineration. Others such as barium, chromium, copper, and lead can be lost to some extent as constituents of particulates in the stack gases (Farrell and Solotto, 1973; Shen, 1979).

Table IV lists the results of analysis of six elements in the plants which were grown on the sludge ash amended soils and respective control soils. The concentrations of boron, molybdenum, and selenium increased most consistently in the crops as a result of the addition of the sludge ashes to the soils. Boron and selenium were also consistently taken up in higher concentrations than controls when this same series of crops were grown on soil amended with soft coal fly ash (Furr et al., 1978).

Table III. Elemental Analysis of Soils and Sludge Ashes

element	element concentration, ppm, dry wt in: Darien soil	Teel soil	Indianapolis sludge ash	Kalamazoo sludge ash
Ag	2.6	1.8	194	93
Al	25710	41100	58600	98820
As	13	11	27	21
Au	0.003	0.01	4.2	0.6
B	8.0	7.0	17	8.4
Ba	362	341	2189	1120
Br	5.6	7.2	2.5	3.8
Ca	33600	15440	101150	57160
Cd	0.2	0.2	31	0.9
Ce	84	81	180	130
Cl	963	720	3336	1100
Co	8.1	11	52	15
Cr	56	51	5019	524
Cs	4.2	3.6	1.6	1.5
Cu	78	138	6991	1421
Fe	30090	26560	52880	17690
Dy	4.8	9.9	4.7	4.6
Eu	1.4	1.5	3.9	4.6
Hf	9.3	9.2	6.0	4.5
Hg	0.30	0.40	0.04	0.04
K	18980	19500	12140	4741
La	26	25	41	39
Lu	0.4	0.4	0.2	0.2
Mg	15430	6050	22620	43540
Mn	172	728	878	668
Mo	2.1	0.5	22	33
Na	4496	6360	7703	4370
Ni	20	25	625	56
Pb	4.8	7.6	1333	406
Rb	125	99	38	10
Sb	0.8	1.0	19	15
Sc	6.5	6.1	4.3	7
Se	4.0	4.8	10	13
Sm	21	27	20	32
Ta	0.9	0.6	0.9	2.3
Th	18	16	15	37
Ti	2251	4858	5270	33810
U	2.3	2.2	6.8	4.6
V	45	70	55	105
W	2.5	1.2	186	43
Yb	2.5	2.2	1.3	1.0
Zn	71	81	9333	4200

The concentrations of cadmium, nickel, and zinc were generally higher in the crops grown on the Indianapolis sludge ash–soil mixture than the respective crops grown on the Kalamazoo sludge ash amended soil. This may be due to the higher concentration of the elements in the Indianapolis sludge ash. Conversely, molybdenum and selenium were generally higher in the plants cultured on the Kalamazoo sludge ash amended soil vs. the Indian-

Table IV. Concentrations of Selected Elements in Crops Grown in Potted Soils Amended with the Sludge Ashes

crop	B	Cd	Mo	Ni	Se	Zn
	element concentration, ppm, dry weight					
Darien Control Soil						
beans	24.5	0.08	0.8	6.60	0.02	33.3
cabbage	21.7	0.42	0.4	1.30	0.03	27.7
carrots	16.5	0.81	0.5	2.00	0.02	20.4
millet grain	5.5	0.01	0.4	2.40	0.02	43.0
millet straw	9.5	0.15	0.7	1.20	0.03	27.0
onions	15.0	0.58	0.2	1.60	0.01	21.3
potatoes	6.0	0.17	0.2	0.40	0.01	15.8
tomatoes	12.5	0.20	0.3	0.28	0.01	13.5
Indianapolis Sludge Ash Amended Darien Soil						
beans	21.7	0.07	4.6	7.00	0.05	28.3
cabbage	23.5	0.69	2.2	0.50	0.03	20.9
carrots	17.5	1.31	0.5	1.90	0.03	26.1
millet grain	4.5	0.01	1.1	4.90	0.03	52.6
millet straw	9.2	0.21	1.5	1.50	0.03	44.5
onions	17.5	0.45	0.2	1.20	0.02	20.7
potatoes	7.5	0.23	0.8	0.21	0.02	17.0
tomatoes	16.0	0.43	0.5	0.64	0.02	17.2
Teel Control Soil						
beans	15.0	0.08	1.8	1.80	0.04	21.4
cabbage	14.0	0.08	1.0	0.18	0.07	7.9
carrots	12.0	0.11	0.4	0.23	0.04	9.9
millet grain	4.5	0.01	0.6	0.61	0.03	30.4
millet straw	6.5	0.05	0.6	0.25	0.04	9.7
onions	10.0	0.15	0.4	0.28	0.02	10.0
potatoes	6.0	0.09	0.3	0.14	0.03	16.4
tomatoes	10.5	0.27	0.6	0.10	0.03	13.3
Kalamazoo Sludge Ash Amended Teel Soil						
beans	26.0	0.05	18.2	1.90	0.12	26.3
cabbage	23.0	0.09	19.0	0.13	0.10	11.1
carrots	15.5	0.08	0.6	0.13	0.11	9.0
millet grain	4.5	0.01	2.2	0.89	0.11	35.5
millet straw	14.0	0.06	5.6	0.55	0.06	14.8
onions	16.0	0.09	2.0	0.14	0.08	10.4
potatoes	5.5	0.09	2.8	0.16	0.10	11.7
tomatoes	10.0	0.14	8.1	0.06	0.08	13.1

apolis sludge ash–soil mixture, possibly reflecting the higher concentration of these elements in the Kalamazoo sludge ash. The pH of both sludge ash–soil mixtures was almost the same (Table II) so the dependence of element availability of soil pH was presumably not a significant factor. Particular plants also appeared to have an affinity for absorption of specific elements. Thus molybdenum concentration in beans, cabbage, millet straw, and tomatoes was higher particularly for the Kalamazoo sludge ash amended Teel soil. Also beans absorbed a higher concentration of boron, molybdenum, and nickel than most of the other crops regardless of treatment, while the grain of millet was consistently highest in zinc. It is possible that concentrations of elements such as cadmium, nickel, and zinc in the plants would have been higher if the sludge ash–soil mixtures had been more acidic since increasing soil acidity tends to mobilize these elements thus increasing their availability for root absorption. It is also possible that many of the elements in sludge ash are present in highly insoluble or refractory compounds formed during the high-temperature incineration process.

Certain of the control crops appeared to absorb somewhat higher concentrations of specific elements than the corresponding plants grown on sludge ash. It is possible that the sludge ash may have served to fix and immobilize a portion of these elements which were natively present in the soil. None of the crops exhibited external symptoms of toxicity while growing on any of the treatments. The above ground portions of each of the crops cultured on the Kalamazoo sludge ash–Teel soil mixture grew notably taller than the corresponding control crops. Although the sludge ashes were very low in nitrogen this enhanced growth may have been due to other nutrient elements present in the ash.

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