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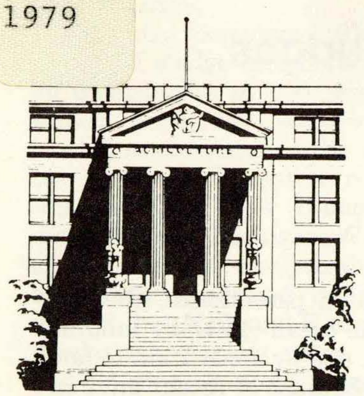

Chemical Composition of Sewage Sludges in Iowa

M. A. Tabatabai and W. T. Frankenberger, Jr.
Department of Agronomy

Agriculture and Home Economics Experiment Station
Iowa State University of Science and Technology
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Chemical Composition of Sewage Sludges in Iowa[1]

by M. A. Tabatabai and W. T. Frankenberger, Jr.[2]

SUMMARY

Knowledge of the chemical composition of sewage sludges produced by wastewater treatment plants in Iowa is essential for future attempts to recycle this material on agricultural land. Sewage sludges produced by treatment plants in 44 Iowa communities, ranging in population from <1,000 to >50,000, were analyzed for 30 constituents to survey the quality of the sludges and to assess the potential of this material as a source of plant nutrients for crop production in this region. Results showed that, expressed on an oven-dry basis, the median values of organic C, and total N, P, K, and S were 31, 2.6, 1.2, 0.3, and 1.1%, respectively, and that the median values for Ca, Mg, Na, and Fe were 7.0, 0.7, 0.2, and 2.0%. Expressed in ppm (mg/kg) of oven-dried sludge in parentheses, the median values for the heavy metals and other trace elements[3] were: Ag(10), As(173), B(100), Be (<0.25), Cd(25), Co(23), Cr(138), Cu(300), Hg(1.3), Mn(319), Mo(13), Ni(28), Pb(250), Se(<25), Sr(<4), V(26), and Zn(1,113). Based on population and sewage sludge estimates, <0.4% of the cropland in Iowa would be required for application of the sewage sludges produced if applied at a rate of 100 kg available N per ha. The variable nature of sewage sludges produced by different communities in Iowa and the presence of potentially harmful amounts of heavy metals in most of the samples analyzed indicate that the chemical composition of every sewage sludge should be known before its application to agricultural land.

INTRODUCTION

Land application of sewage sludge is an old concept that has received public attention in recent years. This attention is derived mainly from the disposal problems associated with the increasing amounts of sewage sludge produced by urban and industrial activities. Generally, four means have been used for disposal of sewage sludge in the United States. With the percentage of the total sewage sludge produced in 1975 in parentheses, the four means are: disposal in the ocean (15%), by landfills (25%), incineration (35%), and by application to land (25%) (see CAST, 1976). Because of recent environmental regulations, restriction will be placed on all methods of sewage sludge disposal. It is anticipated, however, that the percentage of total sewage sludge applied to land will increase.

Sewage sludge contains a wide range of plant nutrients. Application of modest amounts (2 to 10 metric tons per ha) of sewage sludge produced by many municipalities is sufficient to satisfy the plant requirements for P and S and for several minor elements such as Cu, Zn, B, Mn, Fe, and Mo. However, because the N concentration in sewage sludge may vary significantly (both from source to source and from time to time from the same source) and because much of the N is not immediately available to plants, the amount of sewage sludge required to satisfy the crops needs may vary from 5 to 50 metric tons per ha.

In addition to the beneficial elements, sewage sludge may contain toxic elements such as Ni, Cr, Cd, Se, As, Co, Pb, and Hg, which, when added to soils, may accumulate in plants and produce harmful effects by their recycling through the food chain (Chaney, 1973; Page, 1974). The composition and concentration of heavy metals found in sewage sludge is variable and dependent on the source (Carlson and Menzies, 1971; Berrow and Webber, 1972; Purves, 1972; Sommers et al., 1972; Bradford et al., 1975; Sommers, 1977).

A task force organized by the Council for Agricultural Science and Technology (CAST) in 1976 prepared an excellent review of the current knowledge on the potential hazards of the sludge-derived heavy metals to plants and animals. The report concluded that, of the various elements in sludge, Mn, Fe, Al, As, Se, Sb, Pb, and Hg pose relatively little hazard to crop production and plant accumulation when sludge is applied to soils because these elements either have low solubility in slightly acid or neutral, well-aerated soils or, as with Se and Hg, are present in such small amounts that the concentration is low in soils. Other heavy metals, however, such as Cd, Cu, Mo, Ni, and Zn can accumulate in plants and may pose a hazard to plants, animals, and humans under certain circumstances. Therefore, knowledge of the chemical composition of the sludge before its application to land is essential because, at high concentrations, some of these ele-

[1]Projects 2112 and 2274 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa.

[2]Professor and Graduate Research Assistant, respectively. Department of Agronomy, Iowa State University, Ames, Iowa 50011. The authors thank Ervin E. Nesheim for providing the sewage sludge samples used in this study.

[3]The term *trace element* is used here to refer to elements that are, when present in sufficient concentrations, toxic to living systems.

ments may accumulate in plants and produce toxic levels in crops.

Recently, Sommers (1977) conducted a regional survey of sludge composition by obtaining data for 30 constituents in 256 sewage sludge samples obtained from 150 wastewater treatment plants located in six states in the north-central region and two states in the eastern region. The samples were collected from New Hampshire, New Jersey, Indiana, Illinois, Michigan, Wisconsin, Minnesota, and Ohio. Statistical analysis for the mean and median of the data collected in this regional survey indicated that N, P, and K concentrations were within a relatively narrow range, whereas Pb, Zn, Cu, Ni, and Cd concentrations were extremely variable. On the basis of population and of sludge production, Sommers (1977) estimated that $<1\%$ of the agricultural land in most of the states surveyed would be required for application of sewage sludge at the rate of 100 kg of available N per ha. No such survey has been conducted in Iowa.

Iowa has escaped the problems associated with sewage sludge disposal because of its small communities and large rural areas. Nevertheless, application of sewage sludge to agricultural land is becoming more acceptable with increasing cost of fertilizers. Studies of factors affecting fate and reactions of sludge constituents in Iowa soils are essential before recommending sludge application to agricultural land in this region. Knowledge of the chemical composition of sludges produced by Iowa communities is a prerequisite to future attempts to recycle sewage sludge on land. Therefore, this study was carried out to survey the composition of sewage sludge produced by wastewater treatment plants in 44 Iowa communities, ranging in population from $<1{,}000$ to $>50{,}000$.

MATERIALS AND METHODS

The sewage sludge samples analyzed were collected in April and May 1975 from 44 wastewater treatment plants in Iowa (Fig. 1). The samples were liquid sewage sludge collected in plastic containers, brought to the laboratory, and air-dried after the volume was measured. To speed up the air-drying process, the sludge sample was spread on a tray 26 x 39 cm lined with aluminum foil and placed in a well-ventilated hood. A fan was directed toward the hood to enhance evaporation of the liquid. By using this procedure, the liquid sludge normally was air-dried within 16-24 hours. After the solid material was weighed, it was ground to pass a 60-mesh sieve. The dried sludge was stored in a glass bottle at 4°C. When storage of the liquid sludge was required, it was stored 4°C.

For convenience of reporting the results, the sewage sludges studied were divided into five groups according to the population of the municipalities producing the sludge (Fig. 1). With the number of wastewater treatment plants surveyed in parentheses, these groups were: group I, $<2{,}000$ in population (10); group II, 2,000-10,000 (8); group III, 10,000-25,000 (8); group IV, 25,000-50,000 (9); and group V, $>50{,}000$ (9).

The following chemical analyses were performed on each sample: pH by a glass electrode, organic C by the method of Mebius (1960), total N by the method of Nelson and Sommers (1972), NH_4-N and NO_3-N by the methods described by Bremner (1965), inorganic P by the method of Murphy and Riley (1962) after extraction with *N* HCl (0.5 g sewage sludge : 25 ml of *N* HCl) after shaking for 1 hour and filtering (Whatman No. 42) the resulting suspension. For determination of total S, P, Ca, Mg, Na, K, Fe, Ag, As, B, Be, Cd,

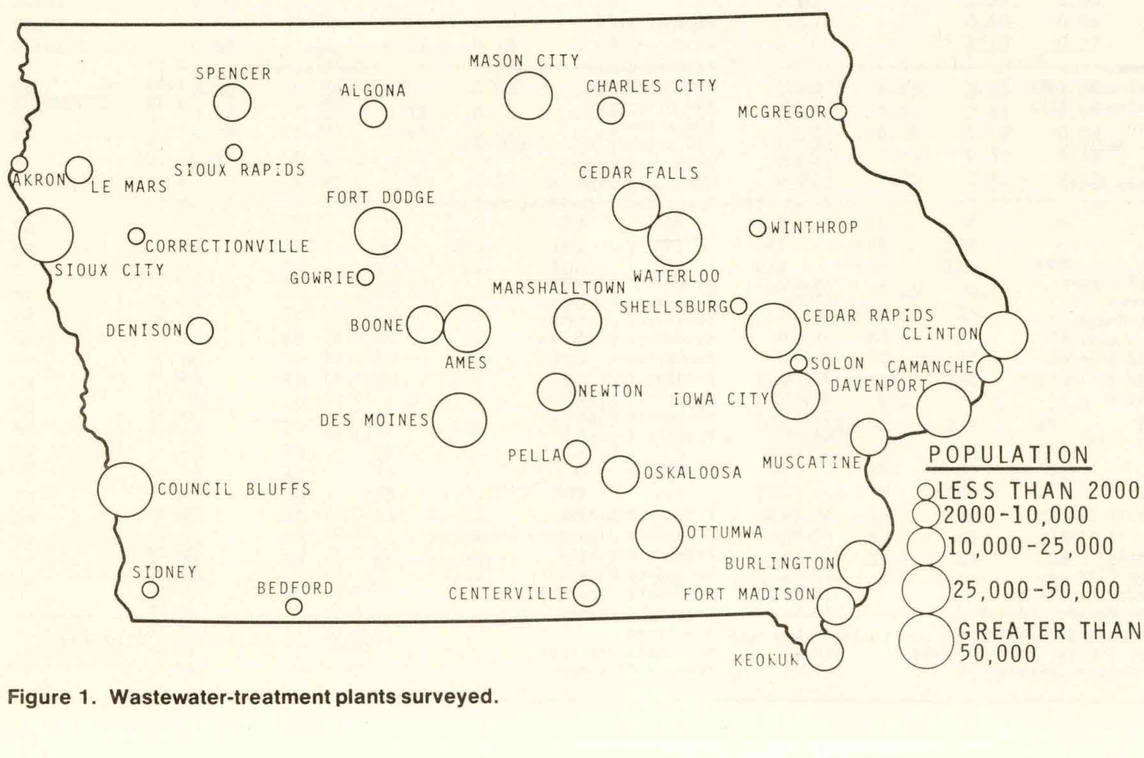

Figure 1. Wastewater-treatment plants surveyed.

Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Se, Sr, V, and Zn, 0.4 g of the air-dried sewage sludge was digested with 2 ml of HNO_3 and 2 ml of $HClO_4$ in a 30-ml Kjeldahl flask. The digest was treated with 3 ml of conc. HCl, boiled to remove the excess HNO_3, and transferred into a 50-ml volumetric flask, and the volume was adjusted with water. The digest thus obtained was analyzed for total S by the methylene blue method of Johnson and Nishita (1952), P by the method of Murphy and Riley (1962), Ca and Mg by atomic absorption spectrophotometry, Na and K by flame photometry, Hg by flameless atomic absorption spectrophotometry, and the rest of the elements by optical emission spectroscopy (Fassel and Kniseley, 1974). When optical emission spectroscopy was used for analysis of the trace elements studied, the lowest result reported for each element was at least 10X the sensitivity of the instrument used. All results reported are expressed on an oven-dry (105°C for 18 hours) basis.

RESULTS AND DISCUSSION

Table 1 shows the treatment plant location, community population, type of sewage sludge sampled, percentage solids, and average daily sewage flow at each wastewater treatment plant studied. Generally, the average daily flow of sewage produced by the treatment plants was proportional to the population of the community producing the sewage sludge. The

Table 1. Description of treatment plants sampled

Sample	City	Population ($\times 10^{-3}$)	Sludge source	Percent solid (%)	Average daily sewage flow [(liter/day) $\times 10^{-6}$]
			Group I		
1-A	Shellsburg	0.74	Imhoff tank	3.10	0.15
1-B	Winthrop	0.75	Imhoff tank	3.15	0.31
1-C	Sioux Rapids	0.81	Imhoff tank	2.57	0.12
1-D	Solon	0.84	Imhoff tank	38.50	0.31
1-E	Correctionville	0.87	Imhoff tank	13.94	0.46
1-F	McGregor	0.99	Imhoff tank	18.69	0.35
1-G	Sidney	1.06	Imhoff tank	9.41	0.19
1-H	Gowrie	1.23	Unheated open digester	8.64	0.77
1-I	Akron	1.32	Aerobic digester	0.73	0.50
1-J	Bedford	1.73	Primary digester	10.69	0.58
			Group II		
2-A	Camanche	3.47	Aerobic digester	1.51	1.58
2-B	Algona	6.03	Primary digester	3.73	2.28
2-C	Denison	6.21	Primary digester	5.72	2.82
2-D	Centerville	6.53	Primary digester	15.00	3.01
2-E_1	Pella (SW)	6.67	Imhoff tank	7.91	0.27
2-E_2	Pella (NE)	6.67	Imhoff tank	8.75	2.66
2-F	Le Mars	8.16	Secondary digester	8.62	3.17
2-G	Charles City	9.27	Holding tank	-----	6.95
			Group III		
3-A	Spencer	10.28	Primary digester	5.21	7.33
3-B_1	Oskaloosa (NE)	11.22	Raw primary	4.73	1.93
3-B_2	Oskaloosa (SW)	11.22	Raw primary	5.10	1.58
3-C	Boone	12.47	Raw primary	2.77	6.18
3-D	Fort Madison	14.00	Raw primary (holding tank)	8.41	11.19
3-E	Keokuk	14.63	Primary digester	6.31	11.19
3-F	Newton-South	15.62	Secondary digester	5.39	8.11
3-G	Muscatine	22.41	Raw primary (holding tank)	10.72	21.62
			Group IV		
4-A	Marshalltown	26.22	Secondary digester	2.87	25.09
4-B	Ottumwa	29.61	Secondary digester	13.64	25.09
4-C	Fort Dodge	31.26	Secondary digester	0.50	14.67
4-D	Mason City	31.95	Secondary digester	0.89	15.83
4-E	Burlington	32.37	Raw primary	10.94	17.37
4-F	Cedar Falls	32.96	Holding tank	5.95	14.28
4-G	Clinton	34.72	Secondary digester	15.62	27.02
4-H	Ames	39.51	Secondary digester	7.04	18.91
4-I	Iowa City	46.85	Primary digester	13.85	19.30
			Group V		
5-A_1	Council Bluffs	60.35	Primary digester	5.49	20.84
5-A_2	Council Bluffs	60.35	Secondary digester, dewatered	27.93	20.84
5-B	Waterloo	75.53	Primary digester	3.74	58.29
5-C	Sioux City	85.93	Secondary digester	17.61	62.92
5-D	Davenport (Main)	98.47	Secondary digester	9.38	67.55
5-E_1	Cedar Rapids (Main)	110.64	Primary digester	1.93	88.78
5-E_2	Cedar Rapids (Main)	110.64	Dewatered	9.63	88.78
5-E_3	Cedar Rapids (Indian Creek)	110.64	Secondary digester	-----	16.60
5-F	Des Moines (Main)	201.40	Primary digester	28.6	157.49

sludge samples were obtained from several sources. These include Imhoff tanks, aerobic digesters, primary and secondary anaerobic digesters, and raw primary sludges. Although direct comparison of the chemical constituents is difficult, especially for N and S, the chemical composition nevertheless should reflect the quality of sludge produced by each community. The sludge composition fluctuates during the day, depending on the rate of generation, which varies with type of treatment employed and kinds and amounts of discharges into the sewage-treatment system. The amount of dry solids available for land application, however, will be roughly proportional to the population served plus the major industrial contributions.

No attempt was made in this study to separate the sewage sludge of treatment plants that receive mainly industrial waste from that of plants receiving primarily residential waste. Sommers et al. (1976), however, showed a significant correlation between the degree of industrialization and elevated metal levels in sludge.

The analyses of the sewage-sludge samples studied are shown in Tables 2-6. Sommers (1977) observed that the mean and median values of many constituents of sewage sludge do not agree because the high and low values may skew the mean and concluded that the true central tendency for the concentration of a particular constituent in sewage sludges may be more adequately represented by the median rather than the mean value. The results obtained in this study (Tables 2-6) show that there is a large degree of variation between the mean and median values of the parameters measured.

The percentage solids of the sludge samples analyzed varied considerably within each population group (Table 1). For example, the percentage solids in group I (population <2,000) varied even within the same stage of treatment (Imhoff tank) from 2.6% in Sioux Rapids to 39% in Solon. Generally, the average daily flow of liquid sewage produced by each population group increased as the size of population increased. Within each group of sludge sampled, however, the sewage flow from the various communities was not always proportional to population of the communities producing the sewage (Table 1).

The analyses of the samples for the five groups of sludges are reported in Tables 2-6. Comparison of the median values of the parameters studied showed that the pH values ranged from 6.3 in group III to 7.0 in group V samples and that the median pH value of all the samples analyzed was 6.9. The median values of organic C varied from 28% in group IV to 39% in group I, with an overall median value

Table 2. Chemical composition of sewage-sludge samples from waste-treatment plants in group I[a]

	Chemical properties of sludge in city indicated[b]											
	A	B	C	D	E	F	G	H	I	J	Median	Mean
pH	5.3	6.7	7.2	6.5	6.2	5.0	5.8	7.0	7.0	7.0	6.6	6.4
Organic C,%	46.7	39.8	25.5	19.7	42.4	45.6	43.8	25.7	38.6	19.6	39.2	34.7
Total N,%	2.58	3.07	2.32	1.74	2.52	2.37	2.58	2.84	4.73	1.99	2.55	2.67
NH_4-N,ppm	2,855	193	1,249	502	768	3,310	3,222	481	275	937	853	1,379
NO_3-N,ppm	200	114	168	129	144	179	198	180	197	260	180	177
Total P,%	0.90	0.97	1.26	0.40	1.52	0.47	0.85	1.99	1.31	1.30	1.12	1.10
PO_4-P,%	0.46	0.74	1.16	0.18	0.43	0.21	0.53	1.10	0.68	0.95	0.61	0.64
Total S,%	0.67	1.45	1.03	0.72	0.69	0.66	0.48	1.75	1.13	0.77	0.75	0.94
							%					
Ca	2.50	6.23	6.15	0.68	5.13	2.50	3.00	7.25	5.25	11.50	5.19	5.02
Mg	0.28	0.50	0.93	0.38	0.34	0.74	0.40	0.66	0.81	0.66	0.58	0.57
Na	0.23	0.26	0.49	0.01	0.03	0.02	0.12	0.46	1.78	0.03	0.18	0.34
K	0.10	0.23	0.65	0.19	0.04	0.13	0.25	0.20	0.59	0.33	0.24	0.27
Fe	0.55	1.94	2.50	1.50	0.74	1.05	0.81	2.25	2.63	2.13	1.72	1.61
							ppm					
Ag	6	63	9	6	10	16	9	6	8	6	9	14
As	94	175	0	163	163	175	188	188	175	0	169	132
B	75	55	100	24	100	75	138	138	100	150	100	96
Be	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Cd	9	28	31	13	13	16	13	20	25	25	18	19
Co	8	20	26	15	9	13	9	23	25	25	18	17
Cr	50	38	25	38	100	50	38	38	38	38	38	45
Cu	163	763	225	300	288	188	713	500	350	138	294	363
Hg	0.2	0.8	1.9	8.4	0.1	1.2	1.3	1.4	0.8	13.4	1.2	3.0
Mn	175	575	313	125	113	88	100	3,500	213	438	194	564
Mo	13	13	13	<1	13	13	13	13	13	<1	13	11
Ni	18	25	25	25	6	10	8	25	31	63	25	24
Pb	140	150	175	190	500	275	175	138	200	288	183	223
Se	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Sr	<4	<4	<4	<4	<4	<4	<4	83	<4	38	<4	15
V	10	23	56	33	13	24	25	35	25	38	25	28
Zn	775	1,375	1,000	625	2,500	1,050	1,000	2,125	875	750	1,000	1,208

[a]Cities with population of <2,000.

[b]For identification of city indicated, see Table 1.

Table 3. Chemical composition of sewage-sludge samples from waste-treatment plants in group II[a]

	Chemical properties of sludge in city indicated[b]									
	A	B	C	D	E_1	E_2	F	G	Median	Mean
pH	5.9	7.4	7.0	6.4	6.6	6.6	7.2	5.8	6.6	6.6
Organic C,%	43.6	31.1	31.9	24.5	25.6	25.6	25.7	40.5	28.4	31.1
Total N,%	5.35	3.04	3.21	4.89	1.69	2.53	3.16	3.94	3.19	3.48
NH_4-N,ppm	2,065	----	201	540	168	567	2,633	3,659	567	1,405
NO_3-N,ppm	141	176	115	117	144	118	482	179	143	184
Total P,%	2.18	2.64	1.08	1.63	1.03	1.12	3.56	1.33	1.48	1.82
PO_4-P,%	1.02	1.29	0.99	0.53	0.81	0.71	3.28	0.72	0.90	1.17
Total S,%	0.63	1.55	1.63	2.26	0.70	1.12	3.38	1.00	1.34	1.53
					%					
Ca	2.69	8.06	6.20	6.75	13.00	9.13	13.50	8.38	8.22	8.46
Mg	0.58	0.80	0.59	0.36	4.38	0.56	0.98	0.45	0.59	1.09
Na	0.49	1.10	0.61	0.16	1.76	0.05	0.58	0.39	0.54	0.64
K	0.34	0.26	0.17	0.22	0.63	0.29	0.36	0.16	0.28	0.30
Fe	1.29	1.74	2.68	2.13	2.00	2.00	1.88	1.24	1.94	1.87
					ppm					
Ag	6	9	11	25	10	25	25	25	18	17
As	138	188	188	138	188	78	188	18	163	141
B	81	350	163	625	400	288	123	50	226	260
Be	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Cd	13	28	28	50	13	38	25	25	27	28
Co	14	19	28	25	25	25	25	15	25	22
Cr	1,000	1,088	31	45,875	50	375	125	88	250	6,079
Cu	413	875	475	738	125	313	400	200	407	442
Hg	1.9	2.3	3.3	3.1	4.9	2.6	0.3	5.5	2.9	3.0
Mn	116	650	225	638	2,625	325	475	3,250	557	1,038
Mo	13	28	13	14	<1	13	<1	13	13	12
Ni	25	38	25	38,750	63	25	38	75	38	4,880
Pb	150	450	106	250	113	200	240	150	175	207
Se	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Sr	<4	<4	<4	3,000	<4	<4	75	44	<4	392
V	11	25	26	50	13	38	25	20	25	26
Zn	2,250	2,750	1,500	1,750	538	2,250	1,250	1,750	1,750	1,755

[a]Cities with population of 2,000-10,000.

[b]For identification of city indicated, see Table 1.

Table 4. Chemical composition of sewage-sludge samples from waste-treatment plants in group III[a]

	Chemical properties of sludge in city indicated[b]									
	A	B_1	B_2	C	D	E	F	G	Median	Mean
pH	7.2	5.2	5.6	6.1	5.0	7.4	6.5	6.9	6.3	6.2
Organic C,%	30.5	46.0	40.9	34.7	36.0	52.9	25.5	25.0	35.4	36.4
Total N,%	2.86	3.01	5.72	2.47	1.64	2.76	2.44	2.91	2.81	2.98
NH_4-N,ppm	835	639	12,000	763	1,423	229	508	3,270	799	2,458
NO_3-N,ppm	62	218	307	105	90	157	218	203	180	170
Total P,%	0.95	1.17	1.79	0.61	0.86	0.94	2.10	0.40	0.95	1.10
PO_4-P,%	0.79	0.68	0.96	0.37	0.46	0.90	1.01	0.20	0.74	0.67
Total S,%	1.93	0.58	0.62	1.06	0.79	0.89	1.46	1.53	0.98	1.11
					%					
Ca	6.24	8.00	5.25	3.63	3.71	1.86	8.38	10.88	5.75	5.99
Mg	0.70	0.31	0.43	0.64	0.40	0.43	1.03	0.60	0.52	0.57
Na	0.73	0.01	0.05	0.12	0.05	0.26	0.21	1.72	0.17	0.39
K	0.31	0.23	0.35	0.17	0.14	0.18	0.29	0.15	0.21	0.23
Fe	3.25	0.81	1.21	2.00	3.01	0.80	3.85	1.58	1.79	2.06
					ppm					
Ag	10	1	8	9	10	8	25	7	9	10
As	175	150	175	175	188	163	96	185	175	163
B	125	75	138	63	80	21	900	25	78	178
Be	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Cd	28	8	13	14	31	8	50	11	14	20
Co	33	9	13	25	30	10	50	16	21	23
Cr	26	25	513	225	725	138	2,488	12,000	369	2,018
Cu	138	150	125	300	313	93	325	438	225	235
Hg	1.2	0.2	0.1	2.0	0.3	0.4	3.4	5.6	0.8	1.6
Mn	275	163	225	163	238	225	600	400	232	286
Mo	13	<1	13	<1	14	13	13	<1	13	9
Ni	25	10	325	18	150	25	1,425	25	25	250
Pb	200	100	125	225	725	288	338	150	213	269
Se	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Sr	<4	<4	50	<4	<4	<4	175	<4	<4	31
V	36	14	25	25	31	19	63	30	28	30
Zn	813	500	500	650	4,625	438	8,625	300	575	2,056

[a]Cities with population of 10,000-25,000.

[b]For identification of city indicated, see Table 1.

Table 5. Chemical composition of sewage-sludge samples from waste-treatment plants in group IV[a]

	Chemical properties of sludge in city indicated[b]										
	A	B	C	D	E	F	G	H	I	Median	Mean
pH	7.1	6.8	6.4	7.0	5.7	6.9	7.4	7.0	7.4	7.0	6.9
Organic C,%	28.0	15.8	40.1	30.2	13.3	31.7	11.6	33.9	11.2	28.0	24.0
Total N,%	3.16	1.01	3.57	3.58	1.00	4.00	0.97	1.52	1.46	1.52	2.25
NH_4-N,ppm	824	515	317	1,030	1,724	1,770	356	871	680	824	899
NO_3-N,ppm	235	70	220	217	111	490	50	13	64	111	163
Total P,%	1.98	1.11	1.55	1.80	0.51	2.30	0.60	1.36	1.59	1.55	1.42
PO_4-P,%	1.66	0.53	0.92	1.27	0.44	1.33	0.27	0.98	0.52	0.92	0.88
Total S,%	1.37	0.66	1.53	1.16	0.30	1.16	0.81	1.16	0.51	1.16	0.96
						-%-					
Ca	8.75	9.88	12.60	9.25	6.36	9.75	5.15	5.55	16.23	9.25	9.28
Mg	0.93	0.74	0.69	1.75	0.86	0.95	1.99	0.75	0.88	0.88	1.06
Na	0.11	0.07	0.45	1.25	0.11	0.09	0.06	0.04	0.06	0.09	0.25
K	0.33	0.63	0.19	0.75	0.19	0.16	0.23	0.16	0.13	0.19	0.31
Fe	3.58	3.13	1.16	1.51	1.38	2.13	2.14	1.66	0.88	1.66	1.95
						-ppm-					
Ag	25	11	25	50	9	6	9	50	51	25	26
As	163	0	150	188	161	188	150	181	188	163	152
B	113	100	100	163	11	88	25	58	20	88	75
Be	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Cd	38	25	13	25	10	38	18	20	13	20	22
Co	38	38	13	13	15	25	23	18	10	18	21
Cr	525	25	188	100	150	225	114	863	50	150	249
Cu	300	125	225	325	100	550	200	513	200	225	282
Hg	0.4	1.3	1.9	3.1	1.5	2.3	0.4	2.0	0.8	1.5	1.5
Mn	750	750	263	225	275	350	288	250	550	288	411
Mo	13	13	<1	13	<1	13	13	73	13	13	17
Ni	18	38	4	38	38	25	25	100	75	38	40
Pb	250	563	325	163	2,275	325	325	103	150	325	498
Se	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Sr	38	<4	88	38	<4	438	<4	<4	<4	<4	69
V	38	53	25	25	19	25	38	26	26	26	31
Zn	1,500	613	2,500	1,750	563	4,500	1,175	988	538	1,175	1,570

[a]Cities with population of 25,000 - 50,000.

[b]For identification of city indicated, see Table 1.

Table 6. Chemical composition of sewage-sludge samples from waste-treatment plants in group V[a]

	Chemical properties of sludge in city indicated[b]										
	A_1	A_2	B	C	D	E_1	E_2	E_3	F	Median	Mean
pH	6.3	6.2	7.8	7.0	6.9	7.5	7.1	----	6.6	7.0	6.9
Organic C,%	35.0	35.2	32.0	20.7	28.5	28.0	21.1	5.6	32.8	28.5	26.5
Total N,%	2.16	1.96	3.84	1.80	3.88	3.82	2.39	0.60	2.81	2.28	2.58
NH_4-N,ppm	1,032	559	883	675	720	455	960	69	1,012	720	707
NO_3-N,ppm	202	123	317	300	94	152	120	69	244	152	180
Total P,%	0.63	0.42	3.11	2.72	0.61	2.37	1.22	2.74	1.17	1.22	1.67
PO_4-P,%	0.35	0.32	2.64	2.42	0.36	1.51	0.56	2.42	1.09	1.09	1.30
Total S,%	0.64	1.36	1.39	0.94	0.96	1.28	1.81	1.10	0.99	1.10	1.16
						-%-					
Ca	8.75	7.88	13.50	13.00	6.00	8.08	6.11	17.36	5.69	8.08	9.60
Mg	0.75	0.69	0.88	0.73	0.64	0.61	0.91	0.49	0.79	0.73	0.72
Na	0.33	0.03	0.38	0.09	0.04	1.06	0.21	0.12	0.24	0.21	0.28
K	0.40	0.31	0.38	0.24	0.25	0.62	0.27	0.13	0.41	0.31	0.33
Fe	1.14	2.13	3.63	1.75	2.25	1.78	2.34	4.56	2.13	2.13	2.41
						-ppm-					
Ag	1	11	16	9	9	9	13	25	46	11	15
As	175	125	188	175	138	171	154	188	150	171	163
B	175	33	313	350	36	130	33	156	40	130	141
Be	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Cd	13	19	38	13	28	54	19	50	41	28	31
Co	13	23	38	25	24	19	24	50	23	24	27
Cr	138	213	338	163	213	600	200	388	350	213	289
Cu	200	138	200	125	188	813	5,125	588	300	200	853
Hg	0.1	0.8	0.7	2.6	1.2	0.4	0.1	0.3	0.3	0.4	0.7
Mn	213	213	325	613	350	388	625	725	363	363	424
Mo	13	13	13	<1	13	21	<1	18	13	13	12
Ni	14	25	38	88	63	35	38	225	75	38	67
Pb	300	300	288	250	625	300	425	288	425	300	356
Se	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
Sr	<4	<4	38	50	<4	51	<4	46	<4	<4	23
V	38	46	25	50	39	26	33	30	38	38	36
Zn	750	763	3,250	1,625	988	2,438	950	1,625	1,625	1,625	1,557

[a]Cities with population >50,000.

[b]For identification of city indicated, see Table 1.

of 31%. Sludge samples of group IV showed the lowest median value for total N (1.5%), but the median values for total N in the other groups of sludges were similar and varied from 2.3% in group V to 3.2% in group II. The median values for NH_4-N, NO_3-N, total P, inorganic P, and total S were similar in the five groups of sludges studied. A summary of the 29 chemical constituents and pH measured in the sludges is presented in Table 7. Expressed as percentage of oven-dried solid material, the median values for Ca, Mg, Na, K, and Fe were 7.0, 0.69, 0.19, 0.25, and 1.97%, respectively.

The composition of Iowa sludges in regard to Mg, Na, and K is similar to that reported for other sewage sludges from the north-central region, but the percentages of Ca and Fe in Iowa sludges are much higher than those reported for 256 sludge samples surveyed by Sommers (1977).

A significant amount of the total N in the sludge samples analyzed was present as NH_4^+ and NO_3^-. The concentrations of NH_4-N and NO_3-N in the samples studied ranged from 69 to 12,000 ppm (median = 768 ppm) and from 13 to 490 ppm (median = 163 ppm), respectively (Table 7). It is likely that NO_3-N is not present in anaerobically digested sludge in the treatment plant, but it is produced when these sludges are stored or during the drying process. Sludges produced under aerobic conditions, however, always contain some NO_3-N. Therefore, it is important to consider the type of sludge treatment when considering the availability of sludge N on application to agricultural land. The concentration of mineral N present in sludge also is related to the method of sludge handling; because of the solubility of salts of NH_4^+ and NO_3^- in sewage sludge, dewatering will lead to a reduction in the amount of mineral N in the solid produced. Also, drying liquid sewage sludge may lead to a marked reduction in the concentration of NH_4-N. This decrease in NH_4-N concentration is dependent on the degree of drying, temperature, and time of drying. Depending on the solid content of the sludge, from 50 to 90% of the total N in liquid sludge may be in organic combination (Sommers, 1977). Studies on fractionation of organic N in sewage sludge indicated that about 90% of this fraction is hydrolyzed in 6*N* HCl (Ryan et al., 1973; Sommers et al., 1972). Organic N compounds such as hexosamines and amino acids account for *ca.* 25 to <10% of the hydrolyzable N. These organic N compounds in sludges seem to be derived from the microbial synthesis responsible for degradation of the organic materials in sewage sludges. However, more than 50% of the organic N compunds in sludges has not been identified.

The total P concentration in the sewage sludge samples analyzed ranged from 0.40 to 3.56%, with a median value of 1.24% (Table 7). Fractionation of the total P to organic and inorganic P indicated that

Table 7. Variability of chemical properties of sewage sludges in Iowa

	Range	Mean	Median	Standard deviation	Coefficient of variation (%)
pH	5.0 - 7.8	6.6	6.9	0.7	11
Organic C,%	5.6 - 52.9	30.5	30.8	10.6	35
Total N,%	0.60- 5.72	2.77	2.58	1.15	42
NH_4-N,ppm	69 -12,000	1,343	768	1,917	143
NO_3-N,ppm	13 - 490	175	163	98	56
Total P,%	0.40- 3.56	1.41	1.24	0.77	55
PO_4-P,%	0.18- 3.28	0.95	0.77	0.68	72
Total S,%	0.30- 3.38	1.13	1.05	0.56	50
			%		
Ca	0.68- 17.36	7.63	7.00	3.81	50
Mg	0.28- 4.38	0.79	0.69	0.64	81
Na	0.01- 1.78	0.37	0.19	0.48	130
K	0.04- 0.75	0.25	0.25	0.17	59
Fe	0.55- 4.56	1.97	1.97	0.90	46
			ppm		
Ag	1 - 63	17	10	15	88
As	0 - 188	150	173	53	35
B	11 - 900	146	100	168	115
Be	<0.25-	<0.25	<0.25	0	0
Cd	8 - 54	23	25	13	54
Co	8 - 50	22	23	10	45
Cr	25 -45,875	1,592	138	7,069	444
Cu	93 - 5,125	438	300	752	172
Hg	0.1 - 13.4	2.0	1.3	2.5	125
Mn	88 - 3,500	540	319	738	137
Mo	<1 - 73	12	13	11	92
Ni	4 -38,750	960	28	5,833	608
Pb	100 - 2,275	312	250	334	107
Se	<25 -	<25	<25	0	0
Sr	<4 - 3,000	65	<4	320	492
V	10 - 63	30	26	12	40
Zn	300 - 8,625	1,607	1,113	1,468	91

a large portion of the total P in sludge is inorganic; the inorganic P concentrations ranged from 0.18 to 3.28%, with a median value of 0.77%, indicating that between 4 and 72% of the total P in the sludges analyzed was organic. Studies of P in Indiana sludges have indicated that only 10 to 30% of the total sludge P in anaerobic sludges is organic P (Sommers et al., 1976). Work by Cosgrove (1973) has shown that about 10% of the organic P in activated sludge could be present as inositol polyphosphates. The inorganic P fraction may be present as Ca-, Fe-, and Al- phosphates and inorganic phosphate adsorbed on amorphous complexes of Fe, Al, and Mn hydrous oxides. Thus, a large portion of sludge P can be extracted with dilute acid solutions (Scott and Horlings, 1975). Therefore, because of the chemical nature of P in sludge solids, sludge handling does not influence the concentration of total P.

The total S content of the sludges analyzed ranged from 0.30 to 3.38%, with a median value of 1.05% (Table 7). The median value is similar to that reported by Sommers (1977) for sludges from the north-central and eastern regions.

Previous work on fractionation of total S in sludge indicated that from 1 to 27% of the total S is inorganic S extractable with 0.1*M* LiCl (Sommers et al., 1977). Expressed as a percentage of total S, the sludge samples analyzed by Sommers et al. (1977) contained from <1 to 35% sulfide S, from 18 to 53% inorganic nonsulfate S, from 18 to 56% carbon-bonded S, from 0 to 35% ester sulfate S and inorganic sulfate S, and from 0 to 42% unidentified organic S. No consistent relationships, however, were found between the amounts of organic C, N, S, and P in sludges (Sommers et al., 1977).

Recent studies by Elseewi et al. (1978) showed that sludge and gypsum supplied comparable amounts of S to alfalfa (*Medicago sativa* L.), white clover (*Trifolium repens* L.), and turnip (*Brassica rapa* L.) when applied to acid and calcareous soils. They found that addition of sludge to S-deficient soils corrected the S deficiency in plants and significantly increased the dry-matter yields. Therefore, it seems that sewage sludge is a potential source of available S to plants.

The concentrations of Na and K in sludge are strongly influenced by sewage sludge source, as shown in the 44 samples studied (Tables 2-6). Most sludges contained <0.5% Na or K. Sludges also contain high concentrations of Ca, Mg, and Fe, and a large proportion of the amounts of these metals present in the sludge solids is derived from alum, $FeCl_3$, lime, etc., added to sludges to facilitate settling and dewatering processes. The five groups of the sludges analyzed did not show any general trends in composition of Ca, Mg, and Fe with population. The ranges and median values (in parentheses) of these elements in the sludges studied were: Ca, 0.68-17.36% (7.0%); Mg, 0.28-4.38% (0.69%); and Fe, 0.55-4.56% (1.97%). The median values found for these elements in Iowa sludges are similar to those reported by Sommers (1977) for sludges from other north-central and eastern communities.

Compared with the median values of trace elements in the 256 sludge samples surveyed in the north-central and eastern regions by Sommers (1977), the median values of trace elements in the Iowa sludges were higher for As, B, Cd, Co, and Mn, and lower for Cr, Cu, Hg, Mo, Ni, Pb, and Zn. The data found for concentration of Hg in Iowa sludges and those reported for sludges from the north-central and eastern regions are perhaps underestimated because the sludges were digested in NHO_3 and $HClO_4$ acids before Hg determination; Hg is not stable under these conditions.

Elements such as B, Co, and Mo in sludges are perhaps beneficial for crop production. Analysis of Iowa sludges for these elements indicated that the concentrations of these elements, expressed in mg/kg of oven-dried sludge, were: B, 11-900; Co, 8-50; and Mo, <1-73. Smaller variability for B and Mo but greater variability for Co have been reported for sludges from wastewater treatment plants in southern California (Bradford et al., 1975). The values reported for B, Co, and Mo in sludges pro-

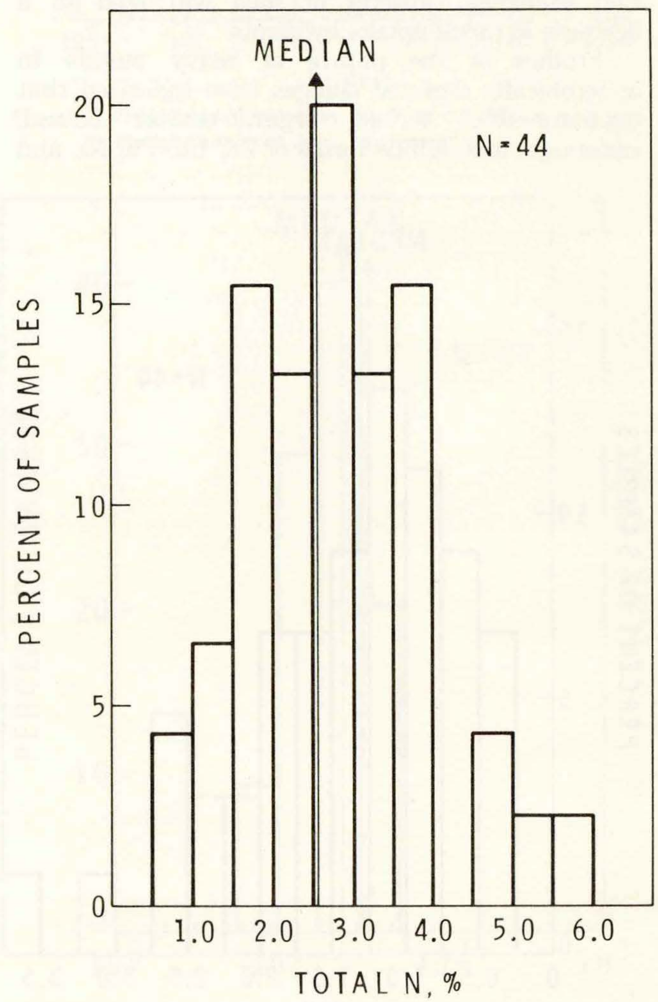

Figure 2. Frequency-distribution diagram for total N in sewage sludges analyzed.

duced in the Los Angeles area ranged from 75 to 680, from 3 to 230, and from 2 to 25 mg/kg, respectively. Not many sludge samples from the north-central region have been analyzed for these elements, but the few samples analyzed for Co and Mo indicate that the concentrations of these elements may range from 1 to 18 and from 5 to 39 mg/kg, respectively (Sommers, 1977).

The concentrations of heavy metals in sludges received considerable attention because some of the heavy metals (e.g., Cd) are not essential for plant growth and development and may accumulate in plants, causing a reduction in yields of crops. Also, high metal concentrations in plant tissue may lead to toxic levels of some elements in the food chain (Page, 1974). Zinc (Zn), copper (Cu), nickel (Ni), and cadmium (Cd) are considered the metals of greatest concern. The first three elements are important because they can be phytotoxic. The concern about Cd is derived from its possible entry into the food chain. However, uptake of sludge-metal by plants depends on several soil properties. Among these properties, soil pH and cation exchange capacity are the two most important. Alkaline pH and high cation exchange capacity of soils will lead to a decrease in metal uptake by plants.

Studies of the nature of heavy metals in anaerobically digested sludges have indicated that exchangeable, sorbed, organic-matter bound, carbonate, and sulfide forms of Zn, Cu, Pb, Ni, and Cd are present in various proportions (Stover et al., 1976). To evaluate the variability in composition of N, P, and K and heavy metals in Iowa sewage sludges, we prepared the frequency-distribution diagrams of these elements in the 44 sludge samples analyzed. These distribution diagrams are shown in Figs. 2-8. Figs. 2-4 show that a significant number of the sludge samples contained N, P, and K close to the median values of these elements, respectively. Similarly, although the concentrations of heavy metals varied considerably among the sludge samples analyzed, a large percentage (30-40%) of the samples contained concentrations of Cu, Zn, Ni, and Cd close to those of the median values for these elements (Figs. 5-8). The sources of these metals in sewage sludges vary, and even the sludges produced by small communities that are relatively free of industries may contain high concentrations of heavy metals such as Cu, which may be derived from household plumbing. The sources of the various metals found in sewage sludges were reviewed recently by Page (1974). The trace-element concentrations in sewage sludges are related to the kinds and amounts of urban and industrial discharges into the sewage-treatment systems. These, in turn, are related to consumer products, industrial processes, and industrial activities.

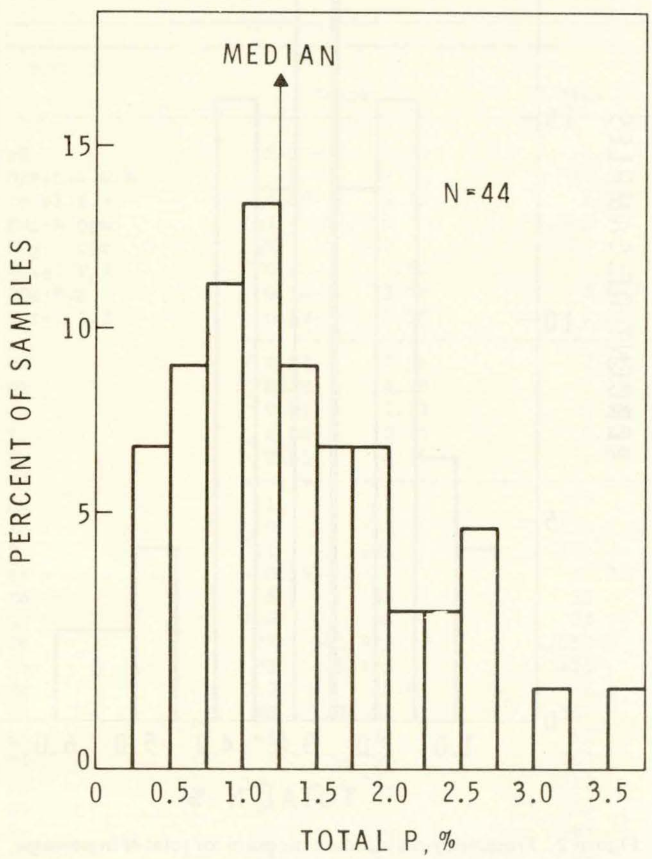

Figure 3. Frequency-distribution diagram for total P in sewage sludges analyzed.

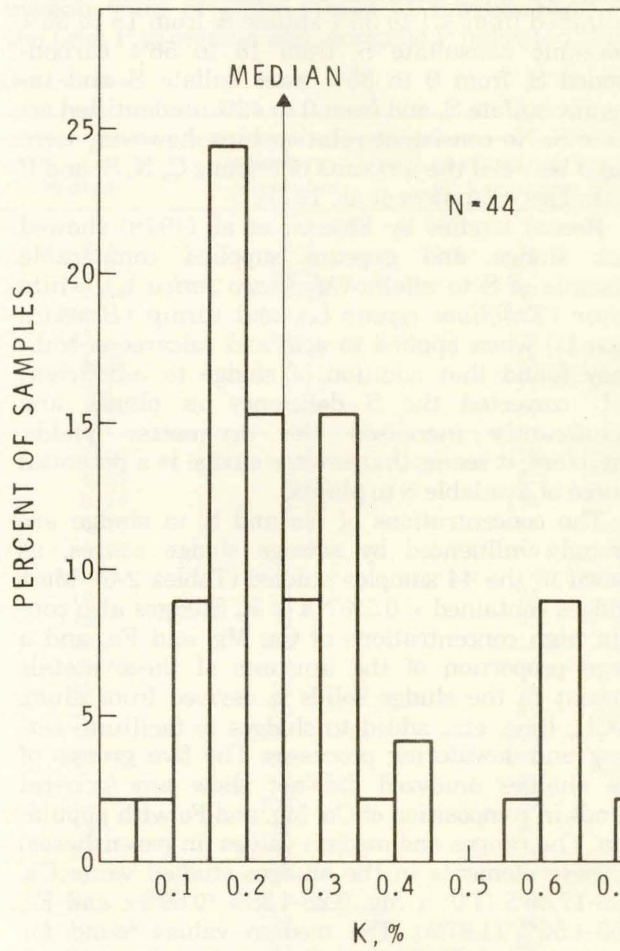

Figure 4. Frequency-distribution diagram of total K in sewage sludges analyzed.

One of the major benefits of using sewage sludge on agricultural land is its plant nutrients, principally N, P, and S. On the basis of total elemental composition, Larson (1974) estimated that the nutrients in sludge produced in the United States in 1973 amounted to 2.5% of the N, 6% of the P, and 0.5% of the K sold as commercial fertilizers. Not all the sludge N, P, and S, however, is available for plant use. Generally, from 1 to 4% of the total sludge N is inorganic and immediately available for plant uptake. To estimate the percentage of agricultural land required for disposal of sludge produced in Iowa by 1985, the following assumptions and calculations were made. It was assumed that 75% of the total population will be sewered and that 100 g of sludge will be produced per capita daily. Assuming that the sludge contains 4% available N (i.e., inorganic N) plus an additional 15 to 20% of this amount in organic form and that the sludge is applied to supply 100 kg of available N per hectare, <0.4% of the total annual cropland would be required for utilization of the sewage sludge produced in Iowa (CAST, 1976).

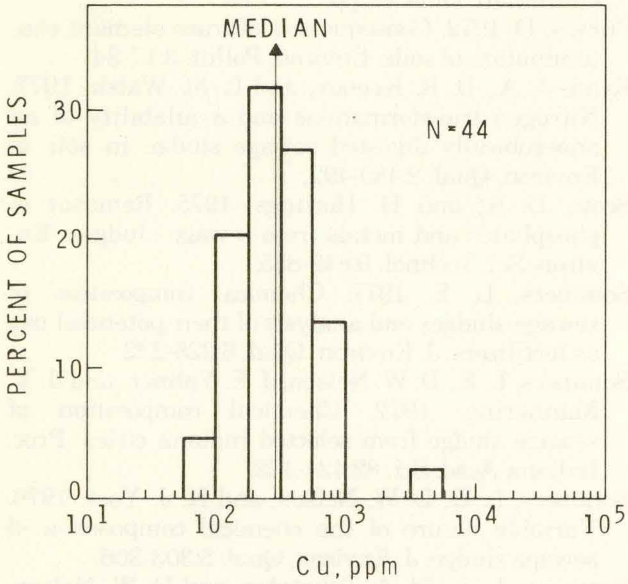

Figure 5. Frequency-distribution diagram for Cu in sewage sludges analyzed ($\log_{10}$ concentration).

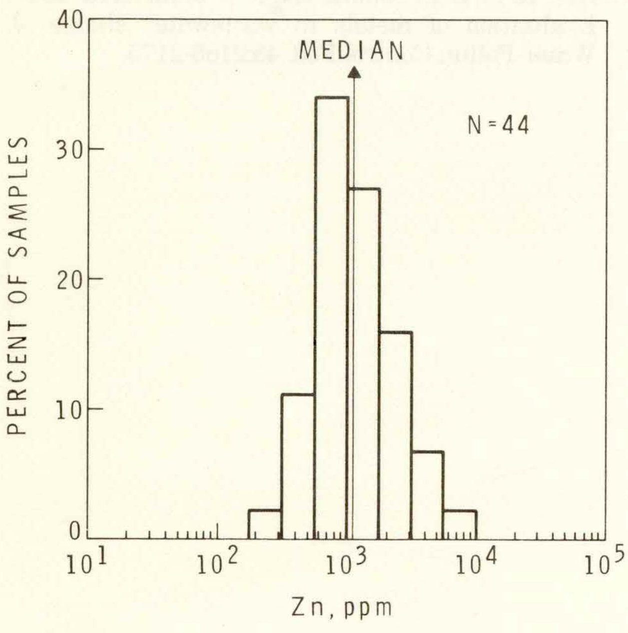

Figure 6. Frequency-distribution diagram for Zn in sewage sludges analyzed ($\log_{10}$ concentration).

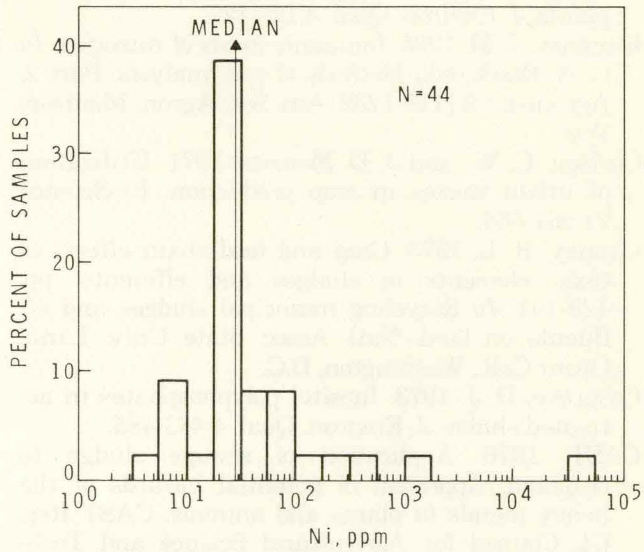

Figure 7. Frequency-distribution diagram for Ni in sewage sludges analyzed ($\log_{10}$ concentration).

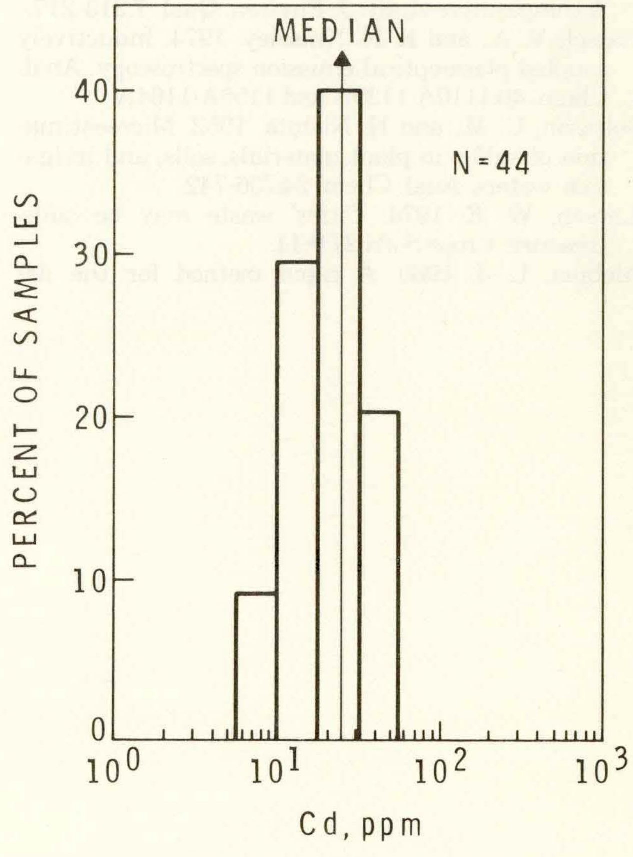

Figure 8. Frequency-distribution diagram for Cd in sewage sludges analyzed ($\log_{10}$ concentration).

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