Effect of Sewage Sludge Applications on Phosphorus and Metal Concentrations in Fractions of Corn and Wheat Kernels[1]

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ABSTRACT

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Grain from corn grown on strip-mined spoil banks amended with digested sludge and wheat grown on silt loam soil, with and without sludge, were fractionated into parts of kernels used in human and animal diets. Corn endosperm and wheat flour contained lower concentrations of cadmium (Cd), zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), chromium (Cr), iron (Fe), manganese (Mn), calcium (Ca), magnesium (Mg), and phosphorus (P) than whole kernels of grain. The germ fraction of corn grain contained significantly higher levels of all elements than other grain fractions, except for Pb, Cr, and Ca. Concentrations of Pb and Cr were not significantly different from those found in the feed and bran fractions and concentrations of Ca were often significantly higher in corn and wheat bran than any other fraction. Sludge applications caused significant increases of all elements in wheat grain except Pb, Cr, and Mn. Flour contained about 25, 14, 28, 47, 55, 41, 43, 18, 35, 12, and 18% of the total amounts of Cd, Zn, Cu, Ni, Pb, Cr, Fe, Mn, Ca, Mg, and P, respectively, accumulated in wheat grain. In general, dry-milling processes have caused reductions in concentrations of essential and nonessential elements in kernel fractions of cereal grains used for human foods and concentration increases in fractions used to supplement animal rations. Information gained from this study will be useful in assessing changes in trace element contents of foods and feedstuffs resulting from crop and soil management practices that cause enhanced concentrations of mineral elements in whole grain.

From the results of analyzing various food groups for concentrations of lead (Pb), cadmium (Cd), zinc (Zn), arsenic (As), selenium (Se), and mercury (Hg), U.S. Food and Drug Administration (FDA) workers concluded that "while the food supply contains less than tolerable intakes of those toxic heavy metals for which recommendations exist, any increases in these trace metal concentrations of food are undesirable" (Mahaffey et al 1975). FDA workers expressed concern about the practice of using municipal sewage sludges as soil amendments because they said "about 23% of the total cadmium intake in the total diet comes from grain and cereal products. Thus, a significant increase in cadmium content of the grains could lead to a substantial increase in the cadmium intake from our food supply" (Jelinek et al 1976). To minimize the food-chain hazard, the U.S. Environmental Protection Agency (EPA) recommended that the use of municipal sewage sludge as a fertilizer or soil amendment on privately owned agricultural lands be limited by cumulative amounts of Pb, Zn, copper (Cu), nickel (Ni) and Cd, added as constituents of sludge (EPA 1977). Much of the concern originated because concentrations of several heavy metals were observed to be increased in corn grain and soybeans where municipal sewage sludge was applied at rates in excess of those needed to supply adequate nitrogen (N) and phosphorus (P) to obtain high yields (Hinesly et al 1972, 1976a). The concentrations reported were for whole grain, but for the most part only the endosperm fraction of kernels are used to produce foods for direct human consumption. Concentrations of trace elements in the endosperm fraction and foods produced from it are relatively low in comparison to those in other millstream fractions that are generally used as animal feedstuffs (Czerniejeski et al 1964, Garcia et al 1974, Waggle et al 1967).

No information was found in the literature where concentration changes of mineral elements in individual parts of the kernel were determined as concentrations changed in whole kernels. It had not been determined whether mineral element concentrations in the endosperm fraction are increased in proportion to enhanced concentrations in whole kernels resulting from changes in cultural practices. The objective of this study was to obtain information

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needed to estimate amounts of Pb, Zn, Cu, Ni, and Cd in human diets containing cereal grain food products made from corn (*Zea mays* L.) and wheat (*Triticum aestivium* L.) grains that contained different concentrations of the several elements. Differences were obtained by selecting hybrids with different capacities to take up Cd and planting them on plots amended with municipal sewage sludge. Mineral element concentrations in wheat grain were varied as a result of growing one variety on soils amended with different

TABLE I

Concentrations of Metals in Whole and Hand-Separated Fractions of Corn Kernels from Single Crosses (1) B73 × Mo17 and (2) C103 × B37 Grown on Normal Soil; (3) B73 × 0h545, (4) R802A × R806, and (5) FRMo17 × FR14A Grown on Strip-Mined Spoil Amended with Sewage Sludge

Single Cross	Cadmium	Zinc	Copper	Nickel (mg/kg, dry weight)	Lead	Chromium	Iron	Manganese
				Whole Kernels				
(1)	<0.08	14.1 ± 1.0	1.5 ± 0.1	1.8 ± 0.3	1.0 ± 0.2	< 0.4	17.1 ± 2.1	2.9 ± 0.2
(2)	<0.08	16.6 ± 1.1	1.9 ± 0.3	1.4 ± 0.1	2.0 ± 0.4	1.1 ± 0.3	16.3 ± 1.9	5.3 ± 0.5
(3)	0.30 ± 0.04	47.1 ± 6.9	1.8 ± 0.2	1.6 ± 0.2	1.3 ± 0.1	0.5 ± 0.2	30.2 ± 1.0	4.8 ± 0.6
(4)	0.65 ± 0.05	41.2 ± 4.6	3.3 ± 0.3	1.8 ± 0.1	1.0 ± 0.1	0.6 ± 0.2	27.8 ± 1.5	5.8 ± 0.6
(5)	0.93 ± 0.14	27.3 ± 2.6	1.8 ± 0.2	1.7 ± 0.2	1.6 ± 0.1	0.8 ± 0.4	21.0 ± 3.1	4.9 ± 0.3
				Degermed Kernels				
(1)	<0.08	3.5 ± 0.1	1.0 ± 0.3	1.3 ± 0.1	1.1 ± 0.2	< 0.4	7.8 ± 1.2	1.0 ± 0.1
(2)	<0.08	4.5 ± 0.1	1.1 ± 0.1	1.2 ± 0.1	1.6 ± 0.4	1.0 ± 0.2	6.7 ± 0.4	2.3 ± 0.3
(3)	0.29 ± 0.07	11.4 ± 1.1	1.3 ± 0.2	0.8 ± 0.1	1.1 ± 0.1	0.6 ± 0.1	7.3 ± 1.0	2.1 ± 0.2
(4)	0.62 ± 0.08	12.2 ± 0.5	2.2 ± 0.1	1.0 ± 0.2	1.6 ± 0.5	0.5 ± 0.1	9.9 ± 1.6	3.1 ± 0.1
(5)	0.78 ± 0.02	9.9 ± 1.0	1.6 ± 0.2	1.2 ± 0.5	1.7 ± 0.4	0.9 ± 0.4	8.9 ± 1.2	2.3 ± 0.2
				Defatted Germ				
(1)	0.50 ± 0.01	172.4 ± 2.0	10.7 ± 0.1	1.6 ± 0.1	5.4 ± 0.8	0.9 ± 0.1	113.2 ± 0.9	17.4 ± 0.3
(2)	0.75 ± 0.05	204.3 ± 1.1	11.5 ± 0.3	1.5 ± 0.3	8.4 ± 1.2	0.8 ± 0.2	118.6 ± 0.2	29.8 ± 0.5
(3)	1.55 ± 0.07	449.5 ± 6.8	8.7 ± 0.4	7.9 ± 0.3	5.5 ± 0.4	1.1 ± 0.1	190.3 ± 5.2	22.5 ± 1.1
(4)	2.44 ± 0.07	369.2 ± 4.2	18.4 ± 0.4	8.4 ± 1.1	3.5 ± 0.4	1.2 ± 0.3	226.5 ± 5.4	28.1 ± 0.2
(5)	4.42 ± 0.05	265.3 ± 4.2	11.9 ± 0.5	5.9 ± 0.4	2.1 ± 0.4	1.5 ± 0.2	158.1 ± 4.4	25.3 ± 0.2
				Oil				
(1)	<0.05	0.62	0.28	<0.25	<0.25	0.8	0.63	0.19
(2)	<0.05	1.31	0.15	<0.25	0.34	1.6	0.22	0.35
(3)	<0.05	0.44	0.34	0.68	<0.25	<0.05	0.10	0.15
(4)	<0.05	0.28	0.15	<0.25	<0.25	<0.05	0.10	0.15
(5)	<0.05	1.08	0.15	0.44	0.29	<0.05	0.10	0.15

TABLE II

Concentrations of Selected Metals in Whole and Fractions of Corn Kernels Separated by Dry-Milling Processes

Grain Source[a]	Cadmium	Zinc	Copper	Nickel (mg/kg, dry weight)	Lead	Chromium	Iron	Manganese
				Whole Kernels				
(1)	0.38 ± 0.04	40.5 ± 2.7	1.7 ± 0.1	1.6 ± 0.1	0.21 ± 0.02	0.38 ± 0.09	32.6 ± 2.4	4.7 ± 0.2
(2)	0.58 ± 0.01	40.9 ± 2.2	2.6 ± 0.1	1.4 ± 0.3	0.60 ± 0.13	0.40 ± 0.09	33.5 ± 3.7	6.3 ± 0.3
				Endosperm				
(1)	0.34 ± 0.07	23.2 ± 0.1	0.8 ± 0.2	1.2 ± 0.2	<0.18	0.24 ± 0.02	27.8 ± 1.8	4.3 ± 0.4
(2)	0.35 ± 0.03	18.3 ± 0.7	1.1 ± 0.2	0.6 ± 0.1	0.30 ± 0.03	0.70 ± 0.30	22.7 ± 1.1	2.9 ± 0.1
(3)	0.17 ± 0.03	24.5 ± 0.7	0.8 ± 0.1	0.8 ± 0.1	<0.18	0.37 ± 0.12	14.2 ± 1.8	3.1 ± 0.1
(4)	0.40 ± 0.01	31.6 ± 0.2	1.7 ± 0.1	1.1 ± 0.3	<0.18	0.40 ± 0.07	21.9 ± 1.5	5.1 ± 0.4
(5)	0.60 ± 0.06	28.3 ± 0.5	1.1 ± 0.1	1.2 ± 0.5	<0.18	0.34 ± 0.05	20.0 ± 0.8	4.9 ± 0.1
				Feed				
(1)	0.61 ± 0.02	73.6 ± 2.8	2.4 ± 0.1	4.5 ± 1.1	0.24 ± 0.04	0.59 ± 0.13	68.3 ± 6.3	12.1 ± 0.7
(2)	1.20 ± 0.06	128.8 ± 8.6	4.4 ± 0.7	1.8 ± 0.6	0.21 ± 0.02	0.64 ± 0.02	70.5 ± 3.8	20.0 ± 2.5
(3)	0.30 ± 0.04	74.1 ± 7.6	1.9 ± 0.3	1.8 ± 0.4	0.21 ± 0.07	0.85 ± 0.22	38.7 ± 1.5	7.9 ± 1.2
(4)	0.75 ± 0.03	66.9 ± 0.3	4.0 ± 0.4	1.5 ± 0.1	0.40 ± 0.15	0.65 ± 0.16	85.1 ± 3.7	10.8 ± 0.3
(5)	1.00 ± 0.02	49.9 ± 4.6	1.9 ± 0.1	1.9 ± 0.9	0.27 ± 0.07	0.39 ± 0.04	41.8 ± 1.8	8.2 ± 0.2
				Bran				
(1)	0.83 ± 0.08	48.9 ± 1.5	2.6 ± 0.1	1.7 ± 0.2	0.44 ± 0.05	0.29 ± 0.05	45.2 ± 1.2	15.0 ± 0.5
(2)	0.97 ± 0.06	42.8 ± 2.8	2.3 ± 0.2	1.0 ± 0.4	1.53 ± 0.39	0.47 ± 0.09	33.7 ± 3.5	11.6 ± 0.4
(3)	0.69 ± 0.02	62.5 ± 1.0	2.6 ± 0.2	1.2 ± 0.1	0.69 ± 0.10	1.37 ± 0.06	34.7 ± 2.4	17.5 ± 0.2
(4)	1.73 ± 0.02	45.8 ± 1.4	4.2 ± 0.1	1.0 ± 0.4	0.37 ± 0.05	0.29 ± 0.08	36.3 ± 0.3	18.3 ± 1.5
(5)	1.90 ± 0.12	38.8 ± 1.7	2.0 ± 0.2	1.0 ± 0.4	0.40 ± 0.01	0.35 ± 0.16	20.6 ± 3.5	15.9 ± 0.4
				Germ				
(1)	1.38 ± 0.16	210.6 ± 12.4	6.6 ± 0.3	7.4 ± 0.4	0.25 ± 0.02	0.67 ± 0.26	98.9 ± 0.4	30.8 ± 0.6
(2)	1.57 ± 0.05	156.5 ± 3.3	5.7 ± 0.1	3.6 ± 0.4	0.35 ± 0.02	0.61 ± 0.07	82.4 ± 1.2	25.3 ± 0.4
(3)	0.73 ± 0.11	207.4 ± 1.7	5.0 ± 0.2	2.9 ± 0.6	0.30 ± 0.04	0.94 ± 0.41	70.7 ± 6.9	23.7 ± 1.0
(4)	1.76 ± 0.06	150.7 ± 4.1	9.0 ± 0.6	3.1 ± 0.3	0.37 ± 0.02	0.47 ± 0.04	80.8 ± 4.0	23.7 ± 1.0
(5)	3.20 ± 0.16	144.8 ± 8.5	6.2 ± 0.9	3.9 ± 0.6	0.29 ± 0.06	0.98 ± 0.40	82.1 ± 2.9	27.0 ± 1.3

[a] Corn grain was obtained from a commercial hybrid grown at two locations (1), (2), and three single crosses (3) B 73 × Oh 545, (4) R802A × R806, and (5) FRMo17 × FR14A grown at the same location. Locations were fields of strip-mined spoil amended with sewage sludge.

rates of sludge. Concentrations of the essential elements iron (Fe), manganese (Mn), chromium (Cr), calcium (Ca), magnesium (Mg), and P were also determined in whole and kernel fractions of grain, because dietary concentrations of these elements are important in ameliorating adverse health effects of excessive levels of some trace elements in animal diets.

MATERIALS AND METHODS

Three corn single crosses, selected on the basis of known capacities of parent lines to accumulate Cd in grain (Hinesly et al 1978), were grown in a field that had been reclaimed from strip-mined spoil. The spoil material had been amended with 262 mt/ha (dry weight equivalent) of anaerobically digested sewage sludge applied over a period of five years. Samples of grain from two other single crosses were obtained from corn breeding studies located on a conventionally fertilized prairie soil at the University of Illinois South Farm.

Subsamples of the above corn grain (100 g) were soaked 36–48 hr in deionized water. The germ was then separated from corn kernels by hand. Whole kernel corn, separated corn germ, and the degermed kernel were dried at 60°C and ground in a Wiley mill to pass a 20-mesh screen. Individual corn germ (12–13g) samples were wrapped in filter paper before placing them in the extraction thimble of a Soxhlet apparatus. Hexane was used as the solvent for extracting oil from the corn germ material. The solvent was removed from the oil under reduced pressure and the defatted corn germ-cake was dried to constant weight in an oven (60°C).

Other samples (4 kg) of corn grain from each of the three single crosses discussed above and another hybrid grown at two locations on reclaimed strip-mined spoil banks amended with sludge were separated into endosperm, bran, germ, and feed fractions by laboratory dry-milling equipment.

Winter wheat was drilled in October, 1976, into the surface of Blount silt loam (Aeric ochraqualf, fine, illitic, mesic) plots that had previously been planted to soybeans each year. Plots had been irrigated with digested sewage sludge for eight consecutive years. When sludge applications were terminated and wheat was planted, one set of replicated plots had received the equivalent of 410 mt/ha and another set had received 205 mt/ha of dry sludge solids. The sludge was applied in previous years as a 3 to 4% solids in suspension by furrow irrigation while soybeans were growing on ridges. When the wheat grain was harvested for determination of yields, subsamples (700 g) were collected and separated into flour, shorts, and bran fractions by a laboratory (Buhler) mill.

Except for corn oil, samples of all corn and wheat grain fractions were digested with a nitric-perchloric acid combination preparatory to analyzing them for concentrations of Ca, Mg, P, Cd, Zn, Cu, Ni, Mn, Cr, Fe, and Pb. Flame atomic absorption spectrophotometry was employed for metal analyses and P concentrations were determined colorimetrically with the use of the vanadomolybdate finish (Greweling 1976). Corn oil samples (2 g) were first ashed by using concentrated nitric acid, as described by Garcia et al (1974), after which they were analyzed for contents of heavy metals by methods used for other grain fractions.

RESULTS AND DISCUSSIONS

Concentrations of eight metals in corn grain and the various hand-separated fractions of kernels are presented in Table I. Metal concentrations in grain from the two hybrids grown on normal, uncontaminated soil were within the range of expected levels (Beeson 1941, Pietz et al 1978). In comparison with these normal levels, corn grain from the three single crosses grown on reclaimed strip-mined lands had high concentrations of Cd, Zn, and Fe. Of the three single crosses grown on sludge-amended spoil banks, only grain from R802A × R806 had a higher concentration of Cu than was found in grain from other sources. Unpublished results from other studies (Agronomy Department, University of Illinois) suggest that differences in metal concentrations were due to sludge treatments rather than differences between soils and strip-mine spoil materials.

As expected from results reported by others (Garcia et al 1974), metal concentrations were highest in defatted germ materials and lowest in the oil extracted from the germ. Except for Pb and Cr, concentrations of metals were lower in the degermed kernel fraction than in whole grain. Removing the germ did not change concentrations of Pb and Cr in the remaining material compared with those found in whole grain. Concentrations of Zn, Fe, and Mn were markedly reduced in the degermed fraction compared with concentrations in whole kernels. The degermed fraction of corn kernels constituted 86 to 89% of the dry weight of whole grain, whereas the proportion of defatted germ ranged from 6.3 to 7.9% and oil from 3.4 to 6.7%. The highest oil content was in the germ of grain produced by the single cross R802A × R806, which was expected because of the hybrid's breeding for this attribute. Even though the defatted germ was a small component of the whole kernel, it contained about 85 and 70% of the total Zn and Cd, respectively, in grain from plants grown on normal soils. Where whole grain concentrations of Zn and Cd were enhanced over those of normal grain as a result of differences in growing conditions and genetic selection, only about 65 and 30%, respectively, of the total grain-Zn and -Cd was contained in the defatted germ fraction. Concentrations of Ni in whole kernels of corn grain varied very little, regardless of source. But the defatted germ of grain produced on strip-mined spoil contained about 30% of the total grain-Ni compared with only 6 to 7% in the same fraction of kernels produced on normal soils. About 50, 40, and 35%, respectively, of the total Fe, Cu, and Mn contained in whole grain resided in the defatted germ fraction.

Further information about the distribution of metal concentrations in grain was obtained from the fractions separated by a dry-

TABLE III
Concentrations of Calcium, Magnesium, and Phosphorus in Whole Corn Kernels and Fractions Obtained from a Dry-Milling Operation

Grain Source[a]	Element Calcium	 Magnesium (mg/kg, dry weight)	 Phosphorus
		Whole Kernels	
(1)	38.0 ± 6.0	1,430 ± 60	3,220 ± 142
(2)	38.0 ± 8.5	1,470 ± 40	3,674 ± 85
(3)	44.0 ± 6.0	1,540 ± 40	3,076 ± 52
(4)	56.1 ± 6.1	1,590 ± 70	3,384 ± 121
(5)	56.0 ± 6.2	1,610 ± 70	3,800 ± 157
		Endosperm	
(1)	26.4 ± 3.4	560 ± 40	1,299 ± 29
(2)	34.5 ± 5.1	420 ± 10	955 ± 28
(3)	9.5 ± 2.5	860 ± 50	1,744 ± 123
(4)	13.1 ± 1.8	1,090 ± 20	2,424 ± 56
(5)	21.5 ± 2.5	1,150 ± 50	2,673 ± 95
		Feed	
(1)	44.8 ± 1.8	1,180 ± 80	4,609 ± 67
(2)	81.7 ± 19.1	4,330 ± 570	10,189 ± 174
(3)	36.2 ± 6.5	2,110 ± 20	4,748 ± 105
(4)	64.1 ± 6.3	2,280 ± 80	5,387 ± 148
(5)	41.1 ± 2.5	2,060 ± 80	5,372 ± 171
		Bran	
(1)	98.4 ± 2.6	980 ± 60	1,902 ± 75
(2)	126.5 ± 9.3	750 ± 30	1,422 ± 35
(3)	129.1 ± 2.6	1,250 ± 30	2,194 ± 56
(4)	168.1 ± 2.6	990 ± 40	1,919 ± 52
(5)	83.3 ± 4.3	840 ± 60	1,616 ± 71
		Germ	
(1)	76.8 ± 9.0	6,700 ± 100	16,990 ± 400
(2)	95.1 ± 1.4	5,740 ± 130	14,177 ± 134
(3)	72.5 ± 5.2	5,890 ± 30	13,667 ± 307
(4)	99.3 ± 3.9	5,720 ± 90	13,893 ± 868
(5)	85.8 ± 9.1	6,970 ± 370	18,354 ± 660

[a] Corn grain was obtained from a commercial hybrid grown at two locations (1), (2), and three single crosses (3) B73 × Oh545, (4) R802A × R806, and (5) FrMo17 × FR14A, grown at the same location. Locations were fields of strip-mined spoil bank amended with sewage sludge.

TABLE IV
Concentrations of Metals in Whole and Fractions of Wheat Kernels Harvested from (1) Control Plots and Plots Irrigated with (2) Intermediate and (3) Maximum Sludge Loading Rates

Grain Source	Cadmium	Zinc	Copper	Nickel (mg/kg, dry weight)	Lead	Chromium	Iron	Manganese
				Whole Kernels				
(1)	0.40 ± 0.05	51.1 ± 6.3	4.3 ± 0.5	0.8 ± 0.2	0.31 ± 0.06	0.8 ± 0.3	40.7 ± 3.0	46.2 ± 4.0
(2)	2.61 ± 0.22	102.1 ± 4.3	5.6 ± 0.2	4.4 ± 0.9	0.41 ± 0.14	0.9 ± 0.5	46.5 ± 5.8	32.6 ± 1.3
(3)	3.44 ± 0.36	131.6 ± 14.8	7.0 ± 0.9	17.7 ± 0.5	0.31 ± 0.05	0.5 ± 0.2	48.6 ± 4.2	38.7 ± 6.0
				Flour				
(1)	0.11 ± 0.01	14.6 ± 2.0	2.0 ± 0.1	1.4 ± 0.1	0.26 ± 0.03	0.51 ± 0.14	30.8 ± 3.3	13.3 ± 0.2
(2)	1.16 ± 0.03	20.8 ± 0.7	2.3 ± 0.1	1.1 ± 0.1	0.24 ± 0.03	0.54 ± 0.03	31.9 ± 6.1	9.2 ± 0.5
(3)	1.48 ± 0.01	21.2 ± 4.8	2.9 ± 0.1	2.6 ± 0.4	0.34 ± 0.03	0.32 ± 0.05	25.8 ± 0.9	9.5 ± 0.2
				Shorts				
(1)	0.79 ± 0.04	141.5 ± 1.9	11.4 ± 0.2	2.4 ± 0.1	0.55 ± 0.05	0.42 ± 0.07	120.4 ± 6.5	108.3 ± 1.1
(2)	5.02 ± 0.08	243.6 ± 1.7	12.8 ± 0.1	9.9 ± 0.2	0.54 ± 0.03	0.45 ± 0.10	110.0 ± 5.7	71.7 ± 0.9
(3)	6.57 ± 0.08	269.7 ± 3.9	13.5 ± 0.1	31.2 ± 0.1	0.61 ± 0.03	0.58 ± 0.14	127.4 ± 2.9	73.1 ± 1.0
				Bran				
(1)	0.58 ± 0.01	165.2 ± 2.6	12.7 ± 0.2	7.2 ± 0.2	0.42 ± 0.07	0.52 ± 0.03	137.3 ± 2.8	117.7 ± 3.6
(2)	6.24 ± 0.05	273.4 ± 1.3	12.6 ± 0.2	15.6 ± 0.2	0.49 ± 0.03	0.32 ± 0.04	118.4 ± 9.2	62.6 ± 2.0
(3)	8.14 ± 0.10	368.0 ± 6.6	15.3 ± 0.1	48.6 ± 0.2	0.35 ± 0.05	0.57 ± 0.25	162.9 ± 7.0	88.7 ± 0.9

milling operation (Table II). All of the grain fractioned by dry milling was produced on sewage sludge-amended strip-mined spoil banks. Grain from each of the three single crosses grown on strip-mined land and used first to obtain the results presented in Table I was included in the dry-milling fractionation study. To complete the five sources, grain from a commercial hybrid grown at two different locations on strip-mined spoil amended with sludge was also included in the dry-milling study. Amounts of endosperm fraction, obtained by dry milling, ranged from 72 to 74% of the dry weight of whole corn grain. This fraction contained flour, meal, and grits, which are usually separated during the milling operation. The feed fraction, containing light materials from the second germ-aspirator and tail-sifter, made up from 14.5 to 15.8% of the total dry weight of grain. Amounts of bran ranged from 3.8 to 4.4% of total grain weight and consisted of light materials from the first three break-aspirators and the first germ-aspirator. The germ fraction contained the heavy materials from the first germ-aspirator and amounts ranged from 7.2 to 7.9% of total grain weights.

Considering 73% extraction of corn grain endosperm by milling processes, amounts of selected elements in the fraction were calculated from concentrations presented in Table II and converted to percent of total amounts in corn grain by use of concentrations presented in Tables I and II for whole kernels. About 49% of the Zn and Cd and 36, 44, 55, and 57%, respectively, of Cu, Ni, Fe, and Mn contained in whole grain had been retained in the separated endosperm fraction. As shown in Table III, endosperm fractions contained 16 to 66 and 21 to 52% of total grain-Ca and -Mg, respectively. These results suggest that amounts of Ca and Mg retained in the endosperm fraction of dry-milled corn grain were related inversely. Only about 24% of the total P in whole kernels of grain from the commercial hybrid, grown at two locations, was retained in the endosperm fraction. In comparison, about twice as much P remained in the endosperm fraction of grain from the three single crosses selected for differences in capacities to accumulate Cd and grown in the same field.

Comparing concentrations in the endosperm (Table II) with those in the degermed fraction (Table I) of grain from the three single crosses grown on strip-mined lands, apparently the former contains less Cd, Pb, and Cr, and more Zn and Fe than the latter. Concentrations of Cu, Ni, and Mn in the endosperm fraction obtained by dry milling were similar to those in degermed corn kernels. Some of the difference may have been due to differences in harvesting. Grain used for the degerming study was hand-harvested in September while grain used for the dry-milling study was harvested with a combine in December.

Results presented in Tables IV and V show that sludge treatments caused increased concentrations of Cd, Zn, Cu, Ni, Fe, Ca, Mg, and P in wheat grain. Milled samples of the grain yielded approximately 66, 21, and 13%, respectively, of flour, shorts, and bran. Flour contained 25, 14, 28, 47, 55, 41, 43, 18, 35, 12, and 18%, respectively, of the total amounts of Cd, Zn, Cu, Ni, Pb, Cr, Fe, Mn, Ca, Mg, and P in whole wheat grain. Relative amounts of Zn, Ni, Fe, Mn, and Ca in flour tended to decrease when concentrations of these elements were enchanced in wheat grain as a result of higher sludge loading rates.

TABLE V
Concentrations of Calcium, Magnesium and Phosphorus in Whole and Fractions of Wheat Kernels Harvested from (1) Control Plots and Plots Irrigated with (2) Intermediate and (3) Maximum Sludge-Loading Rates

Grain Source	Element: Calcium	Magnesium (mg/kg, dry weight)	Phosphorus
		Whole Kernels	
(1)	249 ± 9.8	1,790 ± 80	3,918 ± 140
(2)	435 ± 10.0	1,860 ± 50	5,381 ± 64
(3)	778 ± 19.8	2,080 ± 170	6,349 ± 180
		Flour	
(1)	169 ± 15.1	340 ± 30	1,265 ± 34
(2)	228 ± 1.4	330 ± 10	1,408 ± 94
(3)	287 ± 7.8	370 ± 10	1,572 ± 43
		Shorts	
(1)	564 ± 10.4	3,690 ± 140	8,573 ± 230
(2)	826 ± 28.9	3,720 ± 20	9,733 ± 366
(3)	1,200 ± 54.9	3,730 ± 180	10,258 ± 71
		Bran	
(1)	595 ± 6.5	6,240 ± 20	12,489 ± 374
(2)	1,037 ± 14.2	6,400 ± 50	15,845 ± 67
(3)	1,742 ± 10.4	7,190 ± 60	18,191 ± 261

Except for the endosperm and oil fractions from corn and wheat, insignificant amounts of other fractions are used to prepare human foods. After oil is expelled from the germ, practically all of the germ-cake and remaining fractions are sold as animal feeds. Results from this study suggest that practices that enhance concentrations of inorganic elements in grains may lead to relatively high concentrations in fractions used in animal rations with only nominal increases in portions of grain kernels consumed directly by man. It is unlikely that higher concentrations of inorganic elements in corn and wheat grain than those reported here will be produced as a result of using biologically stabilized municipal sewage sludges as fertilizers and soil amendments. Corn single crosses having high grain-Cd contents were specifically selected for their capacities to accumulate Cd and even the half-rate application of sewage sludge where wheat was grown provided N at levels considered to be too high for the protection of ground-water against contamination with excessive NO_3–N concentrations. There is no evidence confirming the hypothesized development of phytotoxic conditions and health hazards to animals consuming the grain where biologically stabilized sewage sludges have been applied on soils at recommended rates (Hansen et al 1976, Hinesly et al 1976b). As more is learned about requirements, both human and animal mineral nutrition may be improved by selection of cultivars and soil management practices to regulate inorganic element concentrations in diets.

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