Cadmium, Lead, Zinc, Copper, and Nickel in Agricultural Soils of the United States of America

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ABSTRACT

Three thousand forty-five surface soil samples from 307 different soil series were analyzed for Pb, Cd, Zn, Cu, Ni, cation exchange capacity (CEC), organic C, and pH in the course of a study of trace element uptake by major agricultural crops. The soil data from this study are summarized here statistically and in map form to show their interactions and generalized geographic distribution patterns. Amounts of all five metal elements are generally low in the Southeast. A regional high of about 15 mg/kg Pb covers the Mississipi, Ohio, and Missouri River valleys. Higher values for other elements are generally concentrated in the West and in the lower Mississippi River Valley. Maximum Cd levels were found in soils of the coast ranges of central and southern California. Copper levels are noticeably higher in organic soil areas of Florida, Oregon, and the Great Lakes. Nickel and Cu concentrations are high in serpentine soil areas of California. Nickel levels are also somewhat higher in the glaciated areas of the northern great plains and in northern Maine. For the entire dataset, the values of the minimum–maximum, 5th, 50th, and 95th percentiles are as follows: (mg/kg dry soil) Cd, <0.005 to 2.0, 0.036, 0.20, 0.78; Pb, 0.5 to 135, 4.0, 11, 23; Zn, 1.5 to 264, 8.0, 53, 126; Cu, 0.3 to 495, 3.8, 18.5, 95; Ni, 0.7 to 269, 4.1, 18.2, 57; pH (pH units) 3.9–8.9, 4.7, 6.1, 8.1; CEC (cmol/kg) 0.6 to 204, 2.4, 14.0, 135; and organic C % 0.09 to 63, 0.36, 1.05, 33.3. Metal levels generally increased with increasing clay concentration.

EXTENSIVE RESEARCH has been conducted since 1970 to better understand the potential for food-chain transfer of Cd, Pb, and other potentially toxic trace elements. The concern about food-chain transfer arose because: (i) Cd injured Japanese farm families who are rice grain (*Oryza sativa* L.) grown on Cd-contaminated rice paddy soils (Kobayashi, 1978; Tsuchiya, 1978); (ii) U.S. children had high blood Pb levels at least partially due to Pb in commercial foods (Jelinek, 1982); and (iii) cities were considering application of sewage sludge on cropland to achieve less expensive disposal. Early research with land application of Cd-rich sewage sludge indicated grain Cd could be increased as much as 100-fold (Hinesly et al., 1973), and spinach (*Spinacia oleracea* L.) containing high concentrations of Cd was found in a major vegetable production area, the Salinas Valley of California (Jelinek and Braude, 1978).

During the 1970s, the diet model used in the USA by the Food and Drug Administration (FDA) estimated that teen-aged males ingested 39 (range 20–51) μg Cd/d. The FDA scientists argued that these levels were too close to maximum acceptable Cd intakes (52–71 μg Cd/d for 60-kg humans) recommended by the World Health Organization (WHO; FAO-WHO, 1972) to allow any increase in U.S. food Cd (Jelinek and Braude, 1978). Based on the FDA's assumption that dietary Cd and Pb were already high, and would be increased by (i) cropland application of sewage sludge, (ii) use of Cd-rich P fertilizers, and (iii) aerosol emissions and other Cd pollution, the FDA considered the steps required to create an "Action Level" for maximum Cd and Pb in foods. Along with toxicological information on these elements, data on the present background levels of Cd and Pb in crops (normal agricultural products) would be required. Because the "background levels" would be used to identify potentially polluted crops and soils, sites selected for sampling needed to reflect normal agricultural practices, but not known intense Cd or Pb pollution from nonagricultural sources. During that period, it was generally accepted (CAST, 1976) that crops could have increased Cd levels if soil Cd were increased or soil pH decreased. Cation exchange capacity and organic matter also were thought to have some effect on metal uptake. Thus a survey of U.S. crop Cd levels would have much greater value if these data for Cd and Pb were supplemented by data for cation exchange capacity, organic matter and pH at each plant sample site. Analyses of other trace metals that could be conveniently performed would also extend the usefulness of the data. The USDA and USEPA also would benefit from such a survey because other Cd-rich soil and soil properties which cause crop Cd to be high or low might be identified.

In 1978, the USDA, FDA, and USEPA initiated a research program to provide such a database. The USDA Soil Conservation Service (SCS) selected and sampled soils and crops from 3045 sites. These sites represented the major crop producing areas of the USA which contribute a significant portion of Cd to the diet of U.S. citizens. The soils were analyzed by the SCS National Soil Survey Laboratory at Lincoln, NE. Crop samples [carrot (*Dancus carota,* cv. sativa), corn (*Zea mays,* cv. indentata), lettuce (*Lactuca sativa*), onion (*Allium capa*), peanut (*Arachis hypogaea*), potato (*Solanum tuberosum*), rice, soybean [*Glycine max* (L.) Merr.], spinach, sweetcorn (*Z. mays,* cv. saccharata), tomato (*Lycopersicon esculentum*), and wheat (*Triticum* sp.)] were analyzed by the FDA Laboratory at Cincinnato, OH. The present paper summarizes the background agricultural soil metal concentrations and other properties of soil samples collected during that study. Corresponding metal concentrations in the crop samples have been reported previously (Wolnik et al., 1983a, 1985), and soil–crop interactions will be discussed in future publications.

METHODS AND PROCEDURES

Site Selection. The primary purpose of this study was to assess the background levels of Cd and Pb in major food crops and in the soils of their major growing areas. Therefore, great care was taken to select sites without known sources of an-

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Abbreviations: FDA, Food and Drug Administration; SCS, Soil and Conservation Service; CEC, cation exchange capacity; WHO, World Health Organization; LRA, land resource area; LRR, land resource region; NIST, National Institute of Science and Technology; SRM, standard reference materials.

Table 1. Trace metal analyses of National Institute of Science and Technology (NIST) standard river sediment (Standard Reference Material no. 1645, unpublished data).

Element	NIST Result	Measured	Recovery
	mg/kg dry		%
Cd	10.2 ± 1.5	9.8 ± 0.7	96.
Pb	714 ± 28	697 ± 44	98.
Zn	1720 ± 169	1700 ± 270	99.
Cu	109 ± 19	137 ± 4	126.
Ni	45.8 ± 2.9	54 ± 3	117.

thropogenic contamination not normal for agricultural practices. Selected sites were all at least 8 km downwind from any stack emitter (coal fired electric generator, smelter, foundry, etc.), 200 m from U.S. or state highways, 100 m from rural roadways, 100 m from current, abandoned, or known obliterated building sites, and 50 m from field boundaries. Soils with known sludge application were avoided; information about fertilizers, limestone, and pesticides applied to the fields was compiled where known by the farm operator. Seven sites of the same soil series were selected for each crop within counties representative of major growing areas. The replicate sites for one soil series were at least 1.6 km apart whenever possible (not always possible for vegetable crops with limited production areas.)

The crops sampled included carrot, corn, lettuce, onion, peanut, potato, rice, soybean, spinach, sweetcorn, tomato, and wheat. The agricultural census (Bureau of Census, 1977) was used to select counties representative of the major production regions for each crop. Important soil series used to produce the crop in a selected county were then identified by local SCS staff. Although major land resource areas (LRA's) and major land resource regions (LRR's) (see Austin, 1965) were not considered in the selection of sampling locations, specific crops fell within a limited number of LRA's and LRR's because these units represent different soil and climatic regions relevant to production of crops and livestock.

Sample Collection. Sample sites were selected where a healthy mature crop was present on soil areas representing a particular preselected soil series. Soil at the site was examined as necessary to adequately verify the soil series. Each selected site was a 2.5-m by 4-m plot. Plant samples were taken from five randomly selected areas (30 by 60 cm) within this plot. Surface soil samples and one or two subhorizons to a depth of 50 cm were taken beneath the selected plants. These soil samples were composited by horizon to provide a single set of horizon samples for each site. At 61 locations, the composite sample was supplemented by five separate subsamples in order to assess sampling variability. The samples were collected in plastic bags with plastic tools confirmed to contain insignificant amounts of the elements under study. The tools were meticulously cleaned between sample sites to avoid cross contamination between horizons, between sample sites, or between soils and plant tissues. This sampling procedure was replicated at seven sites for each crop series combination studied.

Sample Preparation. The samples were mixed by kneading the soil, while still moist, within the plastic collection bags. Samples were not sieved. A 25-g subsample was obtained by randomly transferring five 5-g scoops of soil to a plastic container and air drying at 35 °C. This dry sample was placed inside a fresh plastic bag and crushed within the bag with a stainless steel roller. After crushing, the sample was mixed by kneading and rotating within the bag, and returned to the plastic container.

Sample Digestion. An approximately 0.3-g subsample from the prepared 25-g "analytical" sample of mineral soils (0.100 g for organic soils) was weighed into a 23-mL Parr[1] Teflon pressure digestion vessel (Parr Instrument Co., Moline, IL). Three milliliters of concentrated HNO_3 ("Ultrex" HNO_3; J.T. Baker Chemical Co., Phillipburg, NJ; containing $<1\mu g$ Cd/kg) were added, the vessel sealed, and the mixture heated overnight (>15 h) at 150 °C. The digestion period was selected after evaluating the effect of digestion time on apparent element concentration. The elements of interest (Cd, Cu, Ni, Pb, Zn) reached a plateau in concentration extracted within 3 to 5 h. The Teflon vessels were weighed before and after digestion to detect possible leakage and to correct for loss of sample digest volume.

[1] Brand names are listed for the benefit of the reader, such listing does not imply endorsement by the USDA.

Table 2. Recovery of Cd added to a reference soil with various additions of reagent Cd or NIST river sediment. The reference soil was analyzed 647 times and was found to contain 0.363 ± 0.022 mg Cd/kg dry soil. Recovery of Cd from NIST River Sediment assumes NIST value of 10.2 mg/kg.

Addition	Calculated Cd	Measured Cd	Recovery of Cd
	mg Cd/kg		%
Reagent	0.838	0.905	108
Reagent	0.868	0.910	105
Reagent	1.40	1.46	104
Reagent	1.43	1.60	112
Sediment	0.828	0.788	94
Sediment	0.966	1.04	108
Sediment	1.22	1.32	118
Sediment	1.37	1.52	111

Lead Analyses. The opened digestion vessel was allowed to stand for about 10 min before transferring an aliquot into the sample tube of an ESA Model 3010A Anodic Stripping Voltameter (ESA, Bedford, MA). This waiting time allowed for volatilization of reaction products that otherwise interfered with the measuring procedure. Three milliliters of 4M Na acetate were then added to buffer the system. A measurement was made after a 1-min plating time on the high-speed rotating electrode; the plating potential was 0.9 V, and the stripping potential was 0.05 V. Calibration was by two different consecutive standard additions to the same sample tube.

Cadmium analysis. Cadmium was analyzed by a Perkin Elmer Model HGA2100 graphite furnace attached to a Model 603 atomic absorption spectrophotometer with deuterium lamp background correction. An automatic sample changer was used and two standard additions were made for each sample. The Cd in each sample was then calculated by the method of standard additions.

Copper, Nickel, and Zinc Analyses. These elements were analyzed with a multielement direct current plasma spectrograph (Beckman Instrument Co., Fulletron, CA; Spectraspan Model III) at wavelengths of 3273, 3414, and 2025 nm, respectively.

Cation Exchange Capacity, Organic Carbon, and pH. These soil analyses were by standard methods of the National Soil Survey Laboratory (Soil Survey Staff, 1972, 1984). Cation exchange capacity (Method 5A8a) was determined by saturating the exchange complex with ammonium ions from pH 7 ammonium acetate, washing with ethanol to remove ammonium from the soil solution, distilling the ammonium from the soil suspension in the presence of NaCl and base into boric acid, and then titrating the ammonium with standardized acid. Organic carbon was determined by a modified Walkley-Black procedure (Method 6A1b) consisting of oxidizing the soil sample with a mixture of potassium dichromate and sulfuric acid, diluting the suspension with water, and back titrating the excess dichromate with standardized ferrous sulfate solution. Soil pH was measured in a 20 mL soil/20 g water mixture after stirring occasionally for 1 h (Method 8C1f).

Quality Assurance for Soil Analysis

The National Institute of Science and Technology (NIST), formerly the National Bureau of Standards, Standard Refer-

Table 3. Average coefficients of variation of field replicate sets for selected ranges of their mean values. The N represents the number of replicate sets.

Cd				Pb				Zn			
Range	N	Mean	CV	Range	N	Mean	CV	Range	N	Mean	CV
					mg/kg						
≤ 0.05	10	0.028	50.3	≤ 10	19	7.8	13.5	≤ 30	21	10.8	26.8
0.05 < 0.10	15	0.074	23.6	10 < 15	20	12.3	8.0	30 < 60	13	45.1	9.7
0.10 < 0.30	20	0.185	11.7	15 < 30	19	16.9	11.3	60 < 90	20	74.5	9.1
≥ 0.30	16	0.641	7.7	≥ 30	3	46.4	12.4	≥ 90	7	115.	6.3
Cu				Ni				pH			
≤ 10	20	4.4	43.9	≤ 10	21	5.6	30.4	< 5.0	12	4.56	2.3
10 < 20	14	15.8	10.4	10 < 20	14	14.0	8.5	5.0 < 5.7	18	5.37	2.5
20 < 50	19	28.7	6.6	20 < 40	20	27.7	8.7	5.7 < 6.5	20	6.01	2.9
≥ 50	8	128.	7.5	≥ 40	6	50.3	4.4	≥ 6.5	11	7.20	1.6
CEC				Organic C							
	cmol/kg				%						
≤ 5.0	11	2.99	7.8	0.35 ≤ 1.0	20	0.76	6.9				
5.0 < 10.0	14	7.87	4.4	1.0 < 2.0	21	1.47	7.1				
10.0 < 20.0	17	15.3	2.9	2.0 < 4.0	13	2.47	6.8				
≥ 20.0	19	68.5	2.5	≥ 4.0	7	25.6	4.6				

ence Materials (SRM's) certified for the elements of interest included only their Standard River Sediment (SRM no. 1645). A quantity of "standard soil" was also prepared and used as source of secondary reference samples. The NIST Certified values and results from the National Soil Survey Laboratory are shown in Table 1. As a further measure of quality assurance, various amount of Cd standard and of the NIST river sediment were added to a test soil to evaluate the ability of the soil analysis method to recover added Cd. Table 2 shows that recovery of both solution Cd and soil Cd was satisfactory.

Some results were below the detection limited for the analytical methods used, 37 samples (from AL, GA, LA, and NC) were less than the 0.010 mg/kg detection limit for Cd. A few samples contained Zn, Cu, and Pb at levels below the detection limits of 3.0, 0.6, and 1.0 mg/kg respectively. In order to include information from these samples in the statistical analysis, results for these nondetected samples were replaced by one-half the detection limit for that element; these values were used for all statistical evaluations. Statistical procedures were selected from the published procedures of the SAS Institute (SAS Inst. 1982).

Quality Assurance for Field Sampling. Seven 2.5-m by 4-m sites were selected to represent each soil series class chosen for study. Within each site, five 30-cm by 60-cm subareas were collected to a depth of 50 cm in not more than three horizon layers. For most sites, these samples were composited to form a single set of two or three horizon samples. For 61 sites, these five subsite samples were analyzed separately. This allowed some measure of the variability within sites, and for a measure of the within-site variance. In all cases, the between site variance differed significantly more than the within site variances ($P < 0.001$).

Table 3 displays the coefficient of variation for these within-site samples for the various analyses. Values for several ranges are given to better represent the data. In general, the lower concentration ranges showed greater variance, but in the median ranges, the variance was on the order of 10%, not unexpected considering the many sources of variation in soil element concentrations.

Mapping Procedures. Maps showing soil element concentrations in the USA were constructed by modifying the SAS mapping procedure to allow plotting particular locations. The

Table 4. Summary statistics for concentrations of microelements and other soil parameters in 3045 surface soil from major agricultural production areas of the USA.

	Cd	Zn	Cu	Ni	Pb	CEC	OC	pH
	mg/kg dry soil					cmol/kg	%	
Geometric mean†	0.175	42.9	18.0	16.5	10.6	13.9	1.37	—
Geo. SD †	2.70	2.35	2.65	2.31	1.74	3.02	3.30	—
Arthmetic mean	0.265	56.5	29.6	23.9	12.3	26.3	4.18	6.26
SD	0.253	37.2	40.6	28.1	7.5	37.6	9.53	1.07
Minimum	<0.010	<3.0	<0.6	0.7	<1.0	0.6	0.09	3.9
1st centile	<0.010	3.2	1.4	2.2	3.0	1.4	0.23	4.3
5th centile	0.036	8.0	3.8	4.1	4.0	2.4	0.36	4.7
10th centile	0.050	12.7	5.3	5.6	5.0	3.3	0.44	5.0
25th centile	0.095	28.4	10.1	9.7	7.0	6.9	0.66	5.4
Median	0.20	53.0	18.5	18.2	11.0	14.0	1.05	6.1
75th centile	0.34	75.8	30.0	27.1	15.0	25.5	1.96	7.1
90th centile	0.56	105.0	62.3	39.6	20.0	47.7	6.20	7.9
95th centile	0.78	126.0	94.9	56.8	23.0	135.0	33.3	8.1
99th centile	1.3	170.0	216.0	154.0	36.0	170.0	41.8	8.3
Maximum	2.0	264.0	495.0	269.0	135.0	204.0	63.0	8.9
Detection limit	0.01	3.0	0.6	0.6	1.0	1.0	0.01	0.1
Percentage < DL	1.64	0.83	0.19	—	0.29	—	—	

† The geometric mean is the antilog of the mean for log-transformed data, the geometric standard deviation is the antilog of the SD obtained for log-transformed data.

Table 5. Comparison of results from the present survey with previously published data on surface soil element concentrations.

	Cd	Zn	Cu	Ni	Pb
	mg/kg dry soil				
Present survey					
Geometric mean	0.175	42.9	18.0	16.5	10.6
Arithmetic mean	0.265	56.5	29.6	23.9	12.3
U.S. soils†					
Geometric mean	—	48.	17.	13.	16.
World soils‡					
Geometric mean	0.62	29.2	59.8	25.8	33.7
Range: Minimum	<0.005§	<1.§	1.5	<1.§	0.1
Maximum	8.1	888.	2000.	390.	1520.
U.S. soils¶					
Typical levels	0.35	15.	50.	30.	50.
Minnesota soils#	0.31 ± 0.21	54.	26.	21.	<25.
Ohio soils††	0.2	75.	19.	18.	19.
Ontario soils‡‡	0.56	53.5	25.4	15.9	14.1
English soils§§	0.9	85.	18.	21.	48.
Welsh soils¶¶	0.5	79.	16.	16.	73.

† From Shacklette and Boerngen, 1984 (p. 1–105); N = 1218.
‡ From Ure and Berrow, 1982.
§ Denotes detection limit, some samples were below this value.
¶ From Sposito and Page, 1984.
# Arithmetic means from Pierce et al., 1982.
†† Arithmetic means from Logan and Miller, 1983; N = 237.
‡‡ Arithmetic means from Frank et al., 1976; N = 296.
§§ Geometric means from McGrath, 1986; N = 2276.
¶¶ Geometric means from Davies and Paveley, 1985; N = 654.

data were reduced for mapping by averaging all data within half degree cells of latitude and longitude. The presence of more than one collection site within a cell reduced the number of mapped locations from 470 collection sites to approximately 150 map points.

The areal divisions were generated by means of a regression tree adapted from an approach developed by Friedman (1979) expanded by Breiman et al. (1984). The procedure works with a data set consisting of the cell average and its corresponding centroid of latitude and longitude. The first step is to examine the entire data set in terms of all possible divisions by latitude or longitude. The areal division is selected which results in the greatest decrease in variance from the original data set. Subsequent divisions are generated by the same procedure until an arbitrarily chosen threshold is reached. The mapping program then creates resulting regions by drawing the partitions. The result is a nonparametric representation of the areas of maximum uniformity as represented by the data set.

RESULTS

Table 4 displays the geometric mean, geometric standard deviation, percentile distribution and detection limits for the entire data set. Geometric mean data are reported because the data better fit a log-normal distribution. Arithmetic mean and standard deviation are also included for comparison, but should not be used to characterize the data. Geometric means are not reported for pH because pH is already a logarithmic value. Arithmetic mean values in Table 4 for Cu, Cd, and to a lesser extent Ni, differ substantially from the geometric means and median values. This reflects distortions resulting from inclusion of local areas of high concentration within the data base. Some soil series were from the Cd-rich Salinas Valley (Mocho and Salinas series). Some soils came from areas where Cu was used as a fertilizer or pesticide, and these soils can be very rich in Cu. In all cases, these concentrations reflect background levels of these soils of *normal agricultural production areas*, however.

Table 5 lists soil element concentrations reported by other researchers. The geometric mean and medians of Table 4 compare well with the geometric means for U.S. soils reported by Shacklette and Boerngen (1984, p. 1–105), with the possible exception of Pb. Their higher soil Pb value may reflect the fact that many of the samples for that study were collected nearer to roadsides than those in the present data (their samples were taken adjacent to interstate highways), and possibly included a contribution from exhaust pollution. Their samples were, however, collected at 20-cm depth which should have avoided most automotive Pb-aserosol contamination in untilled soils.

Tables 6, 7, 8, and 9 summarize the data by state, land resource region, soil order, and soil texture. Figure 1 shows the outlines of the LRR's (Austin, 1965) used to categorize sites for Table 7. Figures 2 through 6 show the geographical distribution of the elements, and Figs. 7, 8, and 9 show similar distributions of soil pH, organic C, and CEC.

DISCUSSION

Distribution of Variance in Soil Cadmium Concentration

Samplings were replicated seven times for each crop and for each soil series where possible. Soil series were therefore the primary unit of soil data presentation. Other categories, however, also can be used to explain the variance of the data set. Figure 10 is a plot of that portion of the total soil Cd variance accounted for by differences within various categories vs. the number of classes within that category. There are three categorical sequences. The taxonomic sequence includes the soil series, soil family, great soil group and soil order. The regional sequence includes the major (LRA's) and their larger groupings, the major LRR's. The political sequence is represented by county and state groupings.

The greatest amount of variation is accounted for by the 307 soil series classes. Higher taxonomic categories with their fewer classes account for lesser amounts of the variance. Nevertheless, the highest taxonomic category, the soil order, still accounts for 45% of the variance with only 9 classes. This is a significant tribute to the usefulness of soil taxonomy to represent soil differences. Grouping Cd by states accounts for nearly the same amount of variance as the soil orders, but utilizes four times the number of classes. The counties account for almost as much variance as the series with fewer classes. This suggests that Cd concentrations in soil are relatively homogeneous across series lines at the local

Table 6. Geometric means for selected soil elements and associated soil parameters in U.S. surface soils by state; histosols and mineral soils evaluated separately because of the large difference in their chemical properties.

State	N	Cd	Zn	Cu	Ni	Pb	CEC	Organic	pH
		mg/kg dry soil					cmol/kg	%	
Mineral soils									
AL	92	0.037 n†	13.9 o	6.0 op	9.4 lm	6.8 l	2.6 l	0.59 n	5.75 k–o
AR	62	0.133 jk	37.6 l	13.5 jk	15.0 f–i	13.8 c–g	12.5 fg	1.03 i	5.72 l–o
AZ	14	0.233 fgh	70.5 b–f	38.1 b	27.9 c	13.3 d–g	13.9 ef	0.35 o	7.68 b
CA	279	0.243 efg	82.7abc	37.3 b	50.5 a	9.7 ij	16.5 de	0.80 jk	7.21 cd
CO	85	0.309 bcd	76.1 a–d	18.0 e–h	14.4 ghi	12.8 efg	12.7 fg	0.74 jkl	7.67 b
FL	30	0.375 b	19.9 n	31.9 bc	8.0 mn	10.1 i	6.8 i	1.51 def	6.29 hi
GA	136	0.037 n	11.4 o	5.3 p	6.8 no	6.7 l	3.2 kl	0.68 k–n	5.88 j–n
IA	70	0.234 e–h	59.2 f–h	19.9 efg	25.7 c	13.4 d–g	27.3 ab	2.49 ab	5.95 j–m
ID	54	0.338 bcd	64.3 d–g	20.9 ef	24.4 c	10.4 hi	16.9 de	1.07 hi	7.35 c
IL	131	0.181 i	52.4 g–j	16.2 g–j	19.1 e	16.0 bc	17.6 d	1.59 cde	6.00 jk
IN	72	0.196 ghi	43.4 jkl	14.3 ij	14.1 hij	12.0 gh	11.8 fg	1.27 fgh	5.71 mno
KS	30	0.313 bcd	51.4 hij	15.2 hij	19.8 de	14.8 cde	19.2 cd	1.15 hi	5.74 k–o
LA	113	0.120 k	39.5 kl	15.1 hij	17.0 e–h	14.5 c–f	16.6 de	1.26 gh	5.61 no
MD	57	0.079 lm	29.5 m	7.7 mn	11.6 jk	10.3 hi	3.2 k	0.72 j–m	5.77 k–n
ME	27	0.165 ij	71.8 b–f	64.8 a	41.2 ab	12.6 fg	13.3 fg	2.23 b	4.47 q
MN	89	0.280 def	68.0 c–f	21.8 de	29.5 c	12.0 gh	33.1 a	2.90 a	5.90 j–m
MO	28	0.268 def	59.5 f–h	18.4 e–h	24.3 cd	19.8 a	19.9 cd	1.69 cde	6.62 fg
MT	29	0.367 bc	74.0 b–e	20.6 ef	25.8 c	10.5 hi	17.1 de	1.41 efg	6.87 ef
NC	163	0.068 m	12.9 o	7.0 no	6.2 o	9.6 ij	5.3 j	1.14 hi	5.17 p
ND	30	0.316 bcd	58.7 f–h	17.8 e–h	25.9 c	8.6 jk	21.8 c	1.83 c	7.13 cde
NE	64	0.332 bcd	50.8 hij	15.2 hij	18.4 ef	13.1 d–g	19.1 cd	1.43 efg	6.43 gh
NJ	114	0.090 l	29.2 m	11.0 kl	8.4 m	13.0 efg	4.6 j	0.60 mn	5.92 j–m
NM	36	0.200 ghi	46.5 ijk	15.4 hij	16.2 e–h	10.5 hi	14.2 ef	0.57 n	8.19 a
NY	74	0.173 i	60.9 e–h	27.0 c	19.7 de	15.3 cd	8.1 hi	1.19 ghi	5.48 o
OH	77	0.357 bcd	82.1 abc	26.2 cd	27.1 c	18.2 ab	18.3 cd	1.74 cd	6.35 ghi
OK	94	0.083 lm	21.0 n	9.7 l	11.1 kl	6.7 l	7.8 hi	0.61 mn	6.38 ghi
OR	88	0.294 cde	67.4 c–f	28.6 c	27.4 c	8.6 jk	22.2 bc	1.07 hi	6.29 hi
PA	40	0.190 hi	83.8 ab	28.3 c	24.6 c	19.6 a	8.7 h	1.26 gh	6.00 jkl
SD	28	0.531 a	91.2 a	29.6 c	40.5 b	14.1 c–f	29.8 a	2.48 ab	6.49 gh
TX	349	0.123 k	30.4 m	9.5 lm	12.5 ijk	7.4 kl	10.9 g	0.65 mnl	7.08 de
WA	122	0.184 i	66.0 def	26.7 cd	26.4 c	8.5 jk	13.1 fg	0.86 j	6.30 hi
WI	94	0.207 ghi	53.5 ghi	17.1 f–i	17.5 efg	10.1 i	12.5 fg	1.58 cde	6.14 ij
All	2771	0.155	41.1	15.5	17.1	10.4	11.1	1.01	6.33
Histosols									
FL	59	0.357 d	97.7 a	94.3 b	8.0 c	6.0 d	138 ab	39.2 a	5.60 a
MI	71	0.908 a	65.9 b	81.2 b	13.1 b	16.0 b	125 b	27.8 c	5.70 a
NY	69	0.751 b	59.2 b	136. a	15.7 a	19.2 a	156 a	35.1 b	5.30 b
WI	65	0.503 c	48.2 c	54.3 c	7.8 c	11.1 c	107 c	33.4 b	5.49 ab
All	264	0.606	64.8	86.9	10.9	12.3	130	33.4	5.52

† Means within a column, within Histosols or minerals soils, followed by the same letter are not significantly different ($P < 0.05$) according to the Waller-Duncan K-ratio T test.

level. The LRR's account for only 29% of the variance with 19 classes but their subdivisions, the LRA's, are markedly more effective in explaining the variance, 73 classes account for 60% of the total variance. This is a reflection of the use of physiographic boundaries to establish many of these areas. From this we may conclude that different categories may be more useful for extending these data, depending on the nature of the concern. For broad representation, the soil order is most effective although the LRR's are more geographically meaningful. For detailed considerations the data is best generalized in terms of the county and soil series. For intermediate generalizations, the LRA's appear most useful.

Geographic Distributions

Amounts of all trace elements, as well as pH, organic C, and CEC, are low in the Southeast. This can be seen from the maps and from Table 7. The higher concentrations show no such consistent regional pattern for all elements taken together. The following discussion will consider the geographic distribution of the individual elements and variables as displayed on the maps of Figures 2 through 9.

Cadmium. Soil Cd concentrations are low in the Southeast (Fig. 2). These soils are quite old, and often have coarse texture and strong acidity. Hodgson (1963) argued that these factors allowed leaching of trace element cations from southeastern soils over millennia. High values are located prinicipally in the Monterrey shale areas of California, known to be a geological source of Cd (Lund et al., 1981) and in Colorado alluvial soils derived from Rocky Mountain sources, probably related to Ag mine residues widely dispersed (see Boon and Soltanpour, 1992).

The lake states organic soils, used primarily for intensive vegetable production, also show accumulations that may be explained by application of phosphate fertilizers containing Cd impurities (Mortvedt et al., 1981). Oregon and Florida also are represented by organic soils that may be high in Cd for the same reason (see Tables 6 and 7). Many Florida soils have received Cd from heat-dried activated sewage sludge which is mixed with other fertilizers to provide some organic N. Many of the commercially available dried sludges have been high in Cd until recent times.

Other areas with moderately high Cd values include

Table 7. Geometric means of selected soil elements and associated soil parameters in U.S. surface soils by land resource regions.

Land resource region	N	Cd	Zn	Cu	Ni	Pb	CEC	OC	pH
		mg/kg dry soil					cmol/kg	%	
Mineral soils									
A Northwestern specialty	58	0.247 cd*	64.9 bc	34.3 b	36.6 b	9.2 efg	19.2 a	2.46 a	5.45 jk
B Northwestern wheat	170	0.202 ef	61.1 cd	23.2 cd	24.0 cd	8.1 ghi	14.5 bc	0.79 ghi	6.68 d
C California subtropical	206	0.254 bcd	90.4 a	43.4 a	64.4 a	10.6 cd	19.7 a	0.91 f	7.07 c
D Western range and irrigated	120	0.291 bc	73.8 b	26.8 c	25.2 cd	9.6 def	13.4 bcd	0.53 l	7.55 b
E Rocky Mountain	40	0.302 b	105. a	19.1 ef	12.7 g	13.2 b	11.3 de	0.64 jk	7.83 a
F Northern Great Plains	73	0.369 a	68.3 bc	20.2 de	27.0 cd	10.0 de	20.8 a	1.76 b	6.81 d
G Western Great Plains	125	0.271 bcd	54.3 d	16.3 fg	17.2 ef	11.8 bc	16.0 b	0.89 fg	7.55 b
H Central Great Plains	181	0.172 fg	36.1 ef	12.6 i	15.3 f	9.2 efg	12.6 cd	0.83 fgh	6.70 d
I Southwest Plateau	180	0.143 g	38.1 ef	10.0 j	12.5 g	7.0 j	11.3 de	0.60 kl	7.46 b
J Southwest Prairie	75	0.046 j	8.8 j	4.9 m	6.5 j	5.0 k	3.7 h	0.42 m	5.71 hi
K Northern lake states	43	0.177 f	40.7 e	15.4 gh	12.3 gh	7.2 ij	7.6 f	1.18 e	5.54 ij
L Lake states	145	0.232 de	60.6 cd	18.2 efg	19.1 e	13.0 b	14.7 bc	1.74 bc	6.31 e
M Central feed grains	407	0.249 cd	61.6 cd	19.7 de	24.1 cd	15.2 a	22.1 a	1.93 b	6.00 f
N East & central farming	21	0.085 h	25.6 g	8.0 k	10.5 h	8.5 fgh	5.3 g	0.68 jk	5.07 l
O Mississippi Delta	116	0.203 ef	61.7 cd	21.1 de	23.7 d	16.4 a	20.1 a	1.30 de	5.95 fg
P South Atlantic & Gulf slope	319	0.047 j	13.5 i	6.3 l	8.2 i	7.7 hij	3.9 h	0.74 hij	5.85 fgh
R Northeastern forage	87	0.176 f	70.8 bc	34.0 b	28.1 c	16.0 a	9.6 e	1.49 d	5.26 kl
S Northern Atlantic slope	118	0.094 h	34.5 f	13.5 hi	11.3 gh	13.0 b	4.3 h	0.71 ij	5.77 gh
T Atlantic and Gulf coast	196	0.065 i	17.1 h	7.6 k	7.8 i	10.0 de	7.6 f	1.13 e	5.30 kl
U Florida subtropical	30	0.375 a	19.9 h	31.9 b	8.0 i	10.1 de	6.8 f	1.51 cd	6.29 e
All Mineral soils	2710	0.156	41.4	15.6	17.4	10.4	11.4	1.02	6.34
Histosols									
K Northern lake states	58	0.742 a	48.5 c	59.6 c	10.3 b	12.2 c	104 c	28.9 d	5.72 a
L Lake states	110	0.693 a	61.9 b	84.7 b	11.6 b	15.0 b	133 b	32.5 c	5.48 b
R Northeastern forage	37	0.691 a	60.7 b	149.0 a	15.6 a	21.7 a	157 a	35.2 b	5.19 c
U Florida subtropical	59	0.357 b	97.8 a	94.3 b	8.0 c	6.0 d	138 ab	39.2 a	5.60 ab
All Histosols	264	0.606	64.8	86.9	10.9	12.3	130	33.4	5.52

* Means within a column, within histosols or mineral soils, followed by the same letter are not significantly different ($P < 0.05$) according to the Waller-Duncan K-ratio T-test.

Table 8. Geometric means for soil elements and associated soil parameters in U.S. surface soils by taxonomic soil order.

Soil order	N	Cd	Zn	Cu	Ni	Pb	CEC	OC	pH
		mg/kg dry soil					cmol/kg	%	
Ultisol	435	0.049 f*	13.8 f	6.2 f	7.4 f	8.0 f	3.5 g	0.78 d	5.60 e
Alfisol	514	0.112 e	31.3 e	10.9 e	12.6 e	9.6 e	9.0 f	0.86 d	6.00 d
Spodosol	37	0.200 d	44.1 d	48.3 b	22.0 cd	10.0 de	9.3 f	1.73 b	4.93 f
Mollisol	936	0.227 cd	54.4 c	19.1 d	22.8 bcd	10.7 d	18.7 c	1.39 c	6.51 c
Vertisol	87	0.239 c	93.1 a	48.5 b	75.9 a	17.1 a	35.6 b	1.32 c	6.72 b
Aridisol	150	0.304 b	70.1 b	25.0 c	24.3 bc	10.6 de	15.2 d	0.63 e	7.26 a
Inceptisol	213	0.230 cd	69.4 b	28.4 c	25.6 b	15.2 b	14.6 d	1.41 c	6.08 d
Entisol	250	0.246 c	65.5 b	21.1 d	21.0 d	10.0 de	11.6 e	0.68 e	7.32 a
Histosol	264	0.622 a	62.6 b	183.2 a	11.3 e	12.5 c	128. a	32.1 a	5.50 e
All	2886	0.178	43.2	18.3	16.9	10.5	14.4	1.41	6.25

* Means within a column followed by the same letter are not significantly different ($P < 0.05$) according to the Waller-Duncan K-ratio T test.

Table 9. Geometric means of soil elements and selected soil parameters in U.S. surface soils by soil texture.

Texture	N	Cd	Zn	Cu	Ni	Pb	CEC	OC	pH
		mg/kg dry soil					cmol/kg	%	
LS	384	0.055 g*	14.9 f	6.0 h	6.2 h	5.5 h	3.4 j	0.57 g	6.02 e
SL	208	0.096 f	26.1 e	10.8 g	11.6 fg	8.3 f	5.6 i	0.76 e	6.04 e
FSL	308	0.107 f	28.3 e	10.3 g	12.1 fg	7.3 g	7.6 h	0.68 f	6.35 cd
SiL	745	0.185 e	50.4 d	18.1 f	19.7 e	12.4 d	13.4 g	1.14 d	6.20 de
L	326	0.199 e	48.4 d	18.6 f	20.6 e	10.6 e	14.2 g	1.16 d	6.52 bc
SiCL	322	0.288 d	76.9 b	28.7 d	35.5 c	16.0 c	27.5 e	1.87 b	6.32 d
C	108	0.289 d	98.0 a	37.6 c	52.0 a	17.7 ab	36.6 c	1.61 c	6.67 b
CL	148	0.294 d	65.3 c	22.7 e	28.4 d	12.1 d	20.3 f	1.13 d	7.23 a
SiC	59	0.388 c	97.7 a	33.6 c	43.1 b	16.4 bc	32.5 d	1.62 c	7.09 a
MUCK	190	0.558 b	65.3 c	75.8 b	11.2 g	10.9 e	118.0 b	29.0 a	5.54 f
SAPRIC	88	0.811 a	59.7 c	97.9 a	12.8 f	18.3 a	133.0 a	30.3 a	5.43 f
All	2886	0.178	43.2	18.3	16.9	10.5	14.4	1.41	6.25

* Means within a column followed by the same letter are not significantly different ($P < 0.05$) according to the Waller-Duncan K-ratio T test.

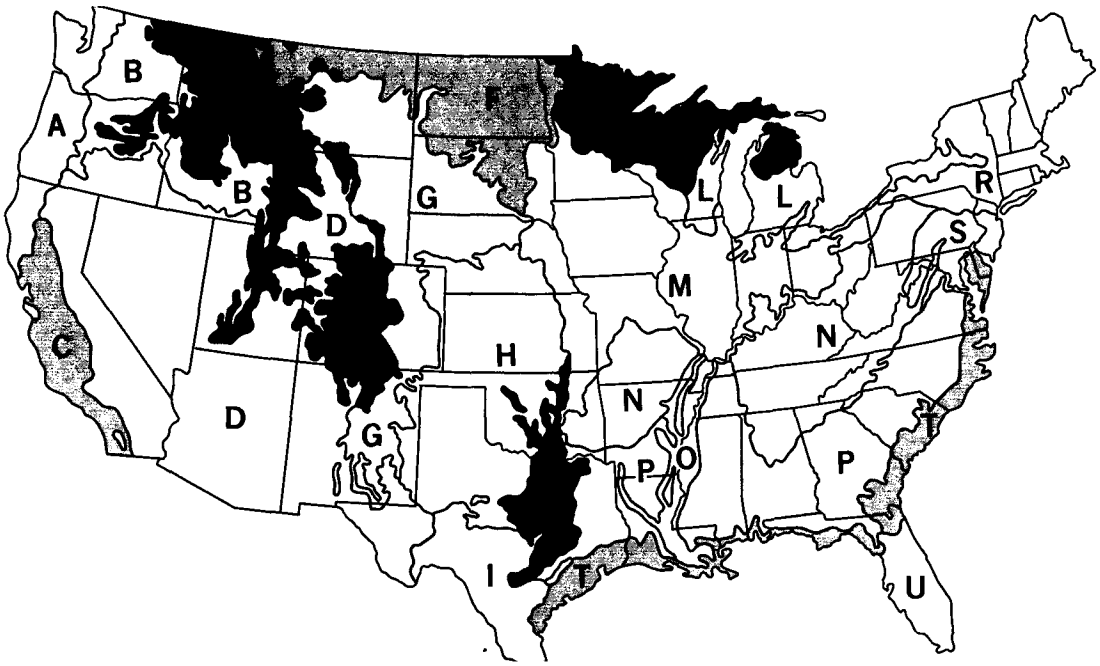

Fig. 1. Major land resource regions of the USA (from Austin, 1965). See Table 7 for legend.

the lower Mississippi River Valley and the glacial areas of the north central states. Khalid et al. (1981) reported 4.8 mg/kg Cd in river sediments taken from below New Orleans. The somewhat higher values in the north central area are in agreement with the work of Pierce et al. (1982), who found that calcareous till in this area contained about 1 mg Cd/kg, presumably as a lattice contaminant in the Ca CO_3. Pierre shales also are a likely source of Cd in this area. Tourtelot et al. (1964) found Cd levels in these shales ranging from 0.3 to 11 mg Cd/kg, with a median value of 0.8 mg Cd/kg. This is only slightly greater than the mean of 0.58 for the delineated area on this map. The few high Cd values in Idaho represent potato-growing soils. These high values may reflect high phosphate fertilizer additions, or possibly use of western phosphate rock which is higher in Cd than eastern sources (Mortvedt et al., 1981). Subsoil Cd concentrations from this area were low, indicating that par-

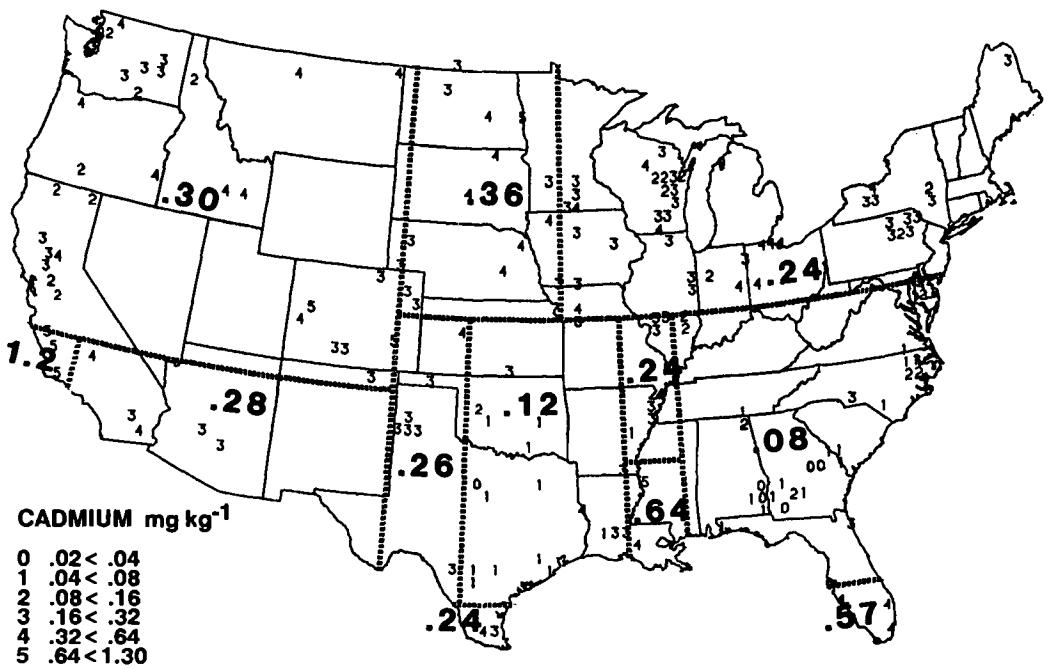

Fig. 2. Geographic distribution of Cd concentration in U.S. soils. The segmented areas represent sequential partitioning of the soil Cd data in subareas with maximum variance reduction from the prepartitioned areas. The bold numbers represent the means of the data within the selected areas (see text), while the small numbers are codes for county average concentrations.

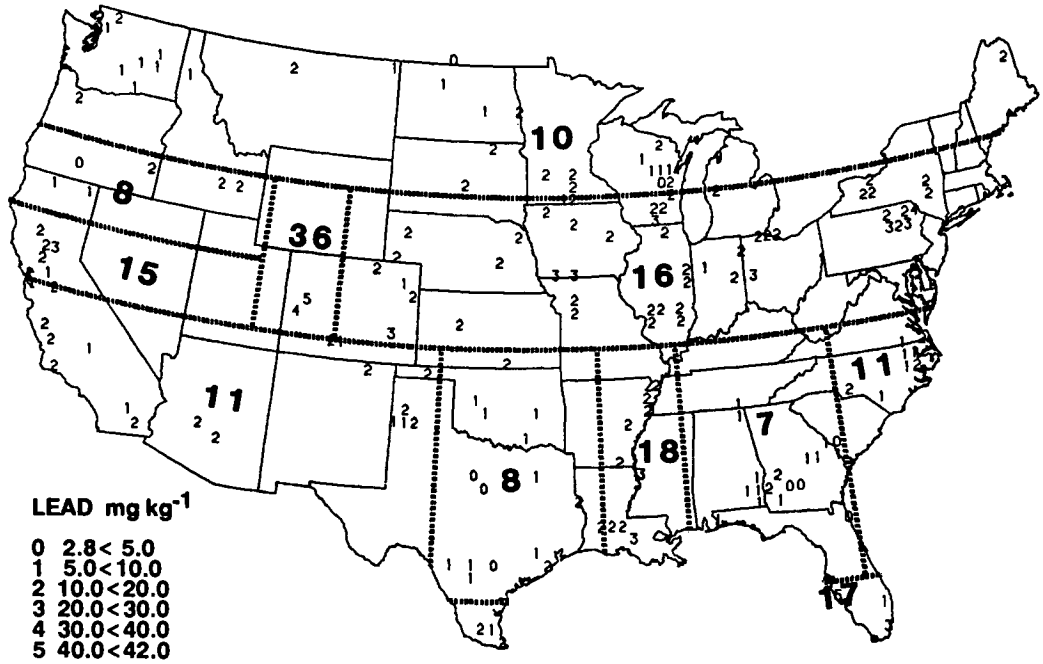

Fig. 3. Geographic distribution of Pb concentration in U.S. soils. The segmented areas represent sequential partitioning of the soil Pb data in subareas with maximum variance reduction from the prepartitioned areas. The bold numbers represent the means of the data within the selected areas (see text), while the small numbers are codes for county average concentrations.

ent material was not the source of the high Cd in surface soils (see discussion of subsoils).

Lead. Lead (Fig. 3) has the lowest concentrations in the Southeast. Lead was locally very high in some of the apple (*Malus* sp.) growing areas of Virginia and West Virginia (some exceed 3000 mg/kg), and these samples were deleted from the U.S. soil data set because they were so anomalous and because apple sampling was not completed before the project ended. Figure 3 shows a broad regional high in the region bounded by the Mississippi, Ohio, and Missouri River valleys. It seems possible that this area endured a greater load of Pb from industrial sources than the more rural western and southern areas. The area also includes the old Pb belt areas

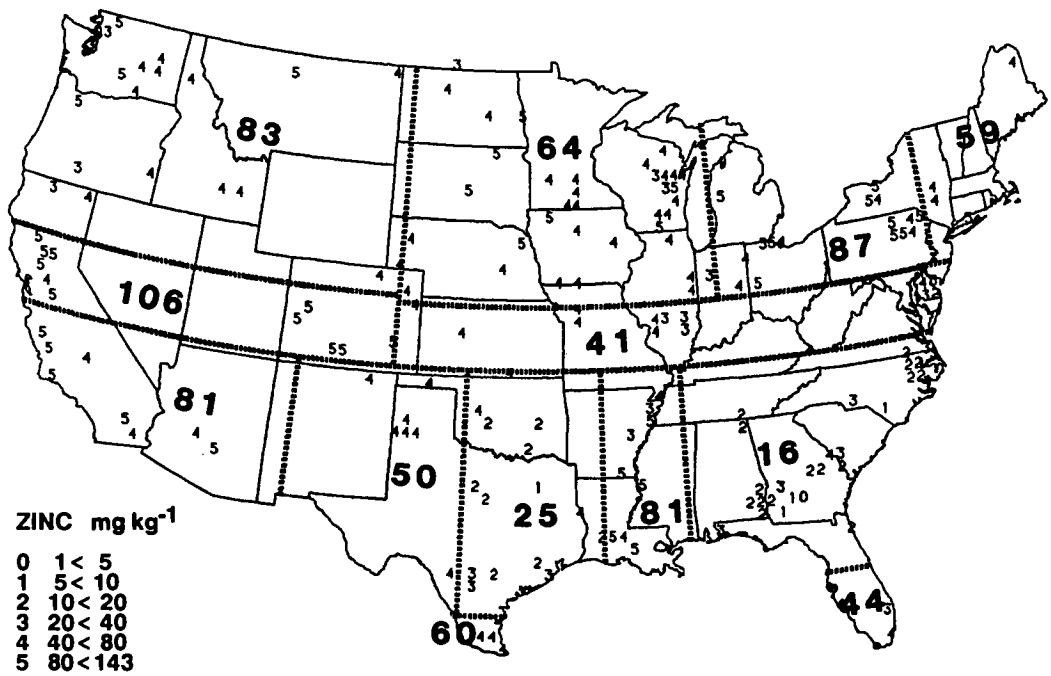

Fig. 4. Geographic distribution of Zn concentration in U.S soils. The segmented areas represent sequential partitioning of the soil Zn data into subareas with maximum variance reduction from the prepartitioned areas. The bold numbers represent the means of the data within the selected areas (see text), while the small numbers are codes for county average concentrations.

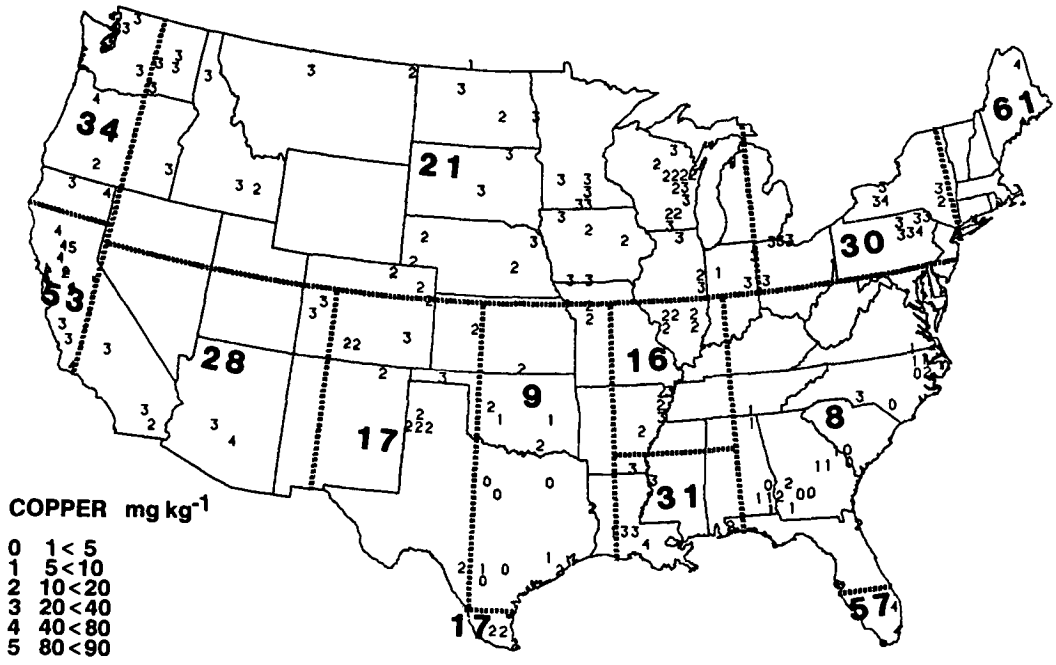

Fig. 5. Geographic distribution of Cu concentration in U.S. soils. The segmented areas represent sequential partitioning of the soil Cu data into subareas with maximum variance reduction from the prepartitioned areas. The bold numbers represent the means of the data within the selected areas (see text), while the small numbers are codes for county average concentrations.

of Missouri, Wisconsin, and Illinois. Tidball (1984) found a geometric mean of 20 mg Pb/kg for 1140 agricultural soil in Missouri. Extension into the industrial northeast is suggestive of industrial pollution.

Zinc. Zinc (Fig. 4) is low in the Southeast and moderately higher in California, the Southwest, Colorado, and in the lower Mississippi valley. The geographic distributions result from the same factors noted above in the discussion of soil Cd distribution. The modestly higher values in the industrial Northeast are consistent with the suggestion of Lagerwerff (1971) that airborne Zn may have contributed to the otherwise anomalous decrease of Zn deficiency in this area. Dispersal of Au and Fe mining wastes rich in Pb, Zn, and Cd is the likely source of these metals in soils of Colorado (see Boon and Soltanpour, 1992).

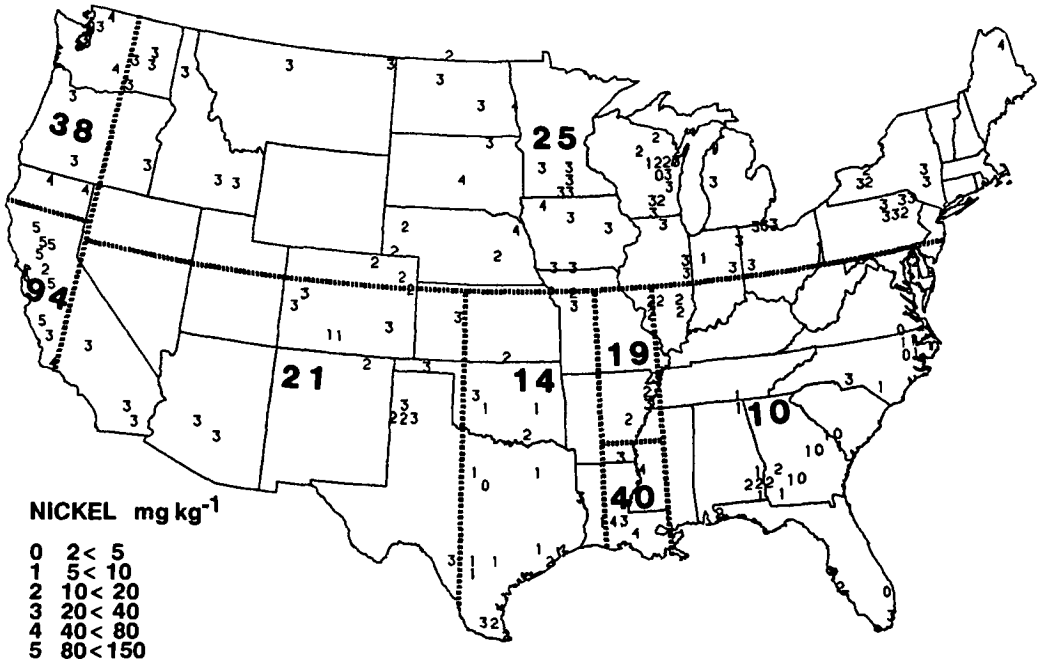

Fig. 6. Geographic distribution of Ni concentration in U.S. soils. The segmented areas represent sequential partitioning of the soil Ni data into subareas with maximum variance reduction from the prepartitioned areas. The bold numbers represent the means of the data within the selected areas (see text), while the small numbers are codes for county average concentrations.

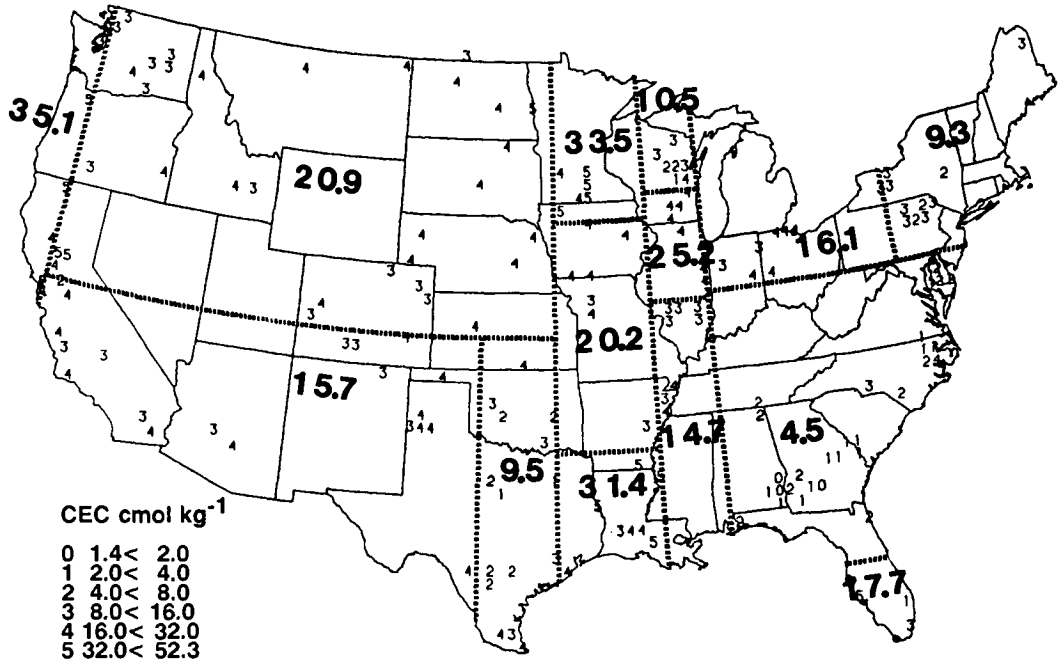

Fig. 7. Geographic distribution of CEC in U.S. soils. The segmented areas represent sequential partitioning of the soil CEC data into subareas with maximum variance reduction from the prepartitioned areas. The bold numbers represent the means of the data within the selected areas (see text), while the small numbers are codes for county average concentrations.

Copper. Copper (Fig. 5) is also low in the Southeast, except in Florida. It is high in the organic soils used for truck crops in Florida, Michigan, and New York (see Tables 6 and 7). This undoubtedly reflects agricultural management practices for these soils which included Cu fertilizers to correct Cu deficiency, as well as Cu containing fungicidal sprays. Copper is also high in California, probably reflecting the greater mineralization and younger geological age of the area. The few high values in the lower Mississippi River Valley may represent industrial contamination.

Nickel. Nickel (Fig. 6) is low in the Southeast and notably higher in parts of California. This probably reflects the broad distribution and influence of the serpentine rocks in California. The high value in northern Maine is consistent with the Ni mines in the area.

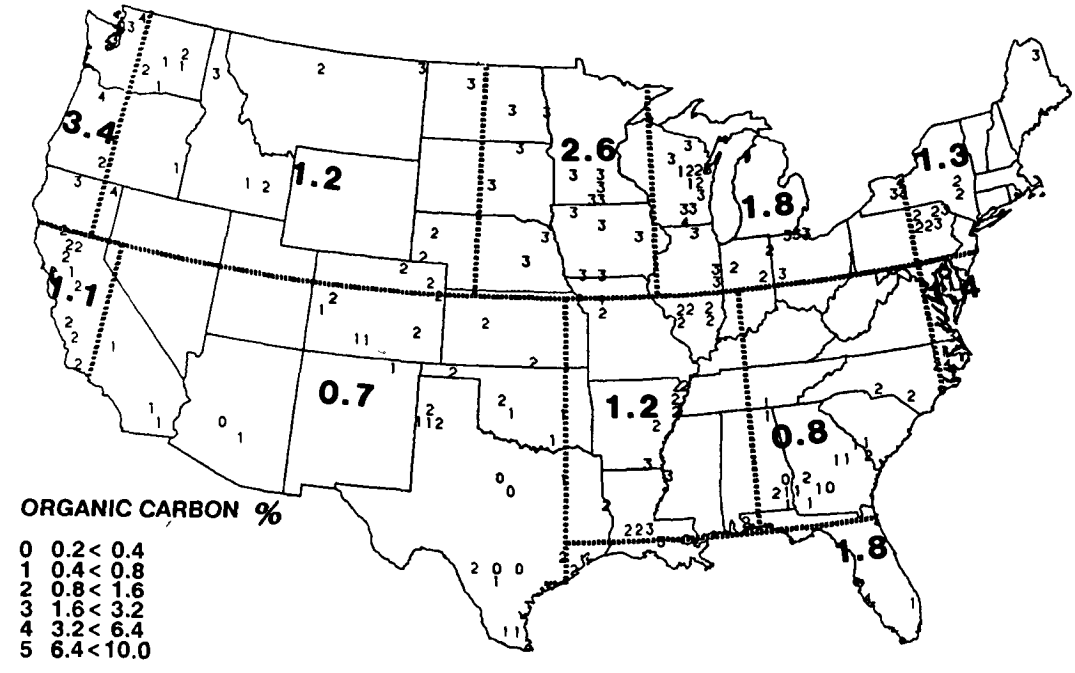

Fig. 8. Geographic distribution of organic C in U.S. soils. The segmented areas represent sequential partitioning of the soil organic C data into subareas with maximum variance reduction from the prepartitioned areas. The bold numbers represent the means of the data within the selected areas (see text), while the small numbers are codes for county average concentrations.

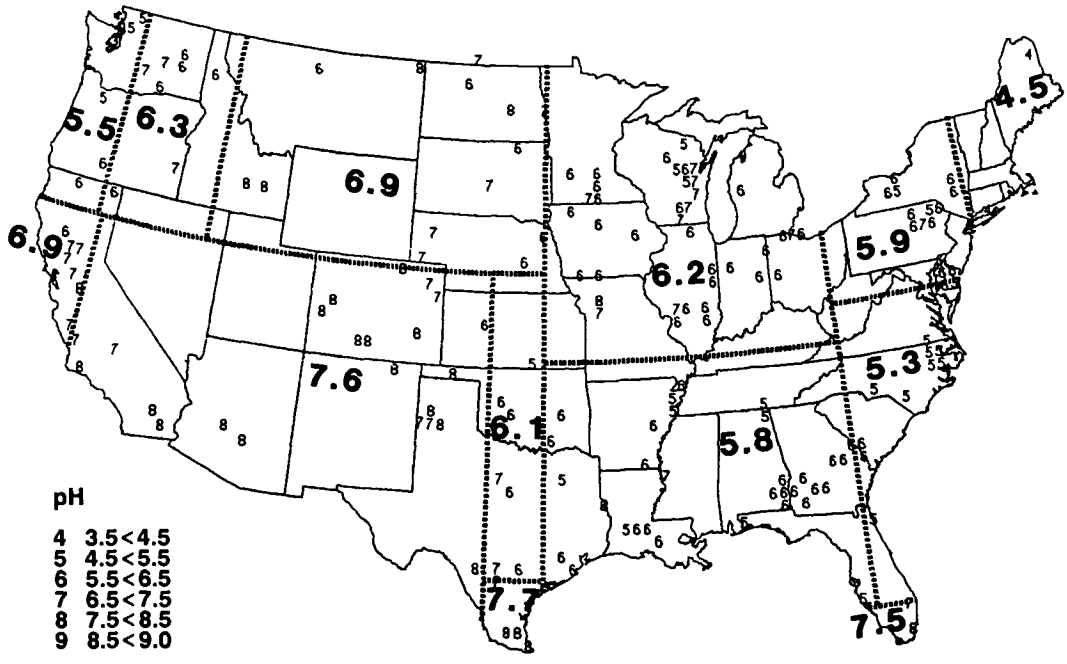

Fig. 9. Geographic distribution of pH in U.S. soils. The segmented areas represent sequential partitioning of the soil pH data into subareas with maximum variance reduction from the prepartitioned areas. The bold numbers represent the means of the data within the selected areas (see text), while the small numbers are codes for county average concentrations.

Cation Exchange Capacity, Organic Carbon, and pH. Figures 7, 8, and 9 show the geographic distribution of soil CEC, soil organic C, and soil pH in the USA, by these data. The broad pattern of strongly acid, low CEC soils in the southeastern USA is quite apparent in these maps. Similarly, organic soils with high organic C and low pH are found in several states. The calcareous soils of the Great Plains and West are separated from more neutral soils of the Midwest.

Distributions by Soil Order

Table 8 lists the element geometric means by soil order of soil taxonomy (Soil Survey Staff, 1975) in order of most highly weathered to least weathered. The concentrations generally follow the orders in the conceived degree of weathering. The strongly weathered soils, Alfisols and Ultisols, are lowest in Cd and in most other elements listed. Of the remaining soils, Aridisols and Histosols have higher Cd levels. The dry Aridisols have not undergone much weathering and the Histosols are high partly because data are reported on a weight rather than on a volume basis. Surface oxidation of organic C in the aerobic layers of Histosols may concentrate Cd in the surface of these soils; this magnifies what is never- the- less a real accumulation of Cd, presumably resulting from fertilization practices.

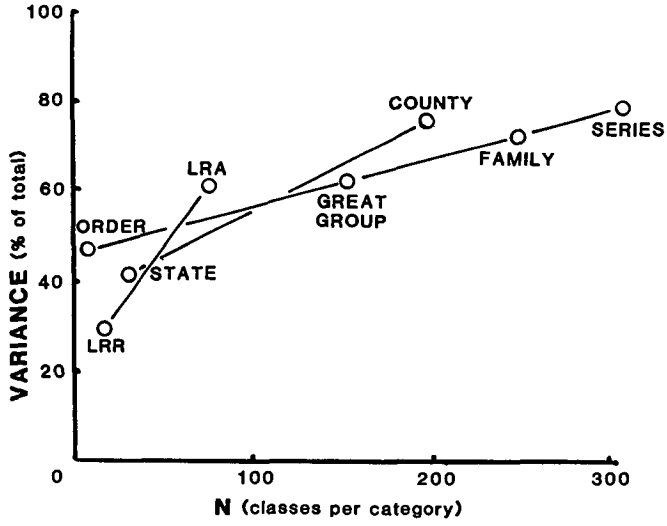

Fig. 10. Distribution of the variance of soil Cd concentration in relation to number of classes within geographic, political, and soil taxonomic categories.

Distributions by Soil Texture

The correspondence between soil texture and Cd shown in Table 9 is paralleled somewhat by other heavy metals, CEC, and organic matter. This is consistent with the expectation that most of the heavy metals in soil are associated with the clay fraction (probably adsorbed on the Fe and Mn hydrous oxide surface coatings on clay particles) or the organic matter. It should be noted that the Southeast included a higher proportion of light-textured soils than other regions. The texture effect and possible weathering effects are thus somewhat confounded.

Log-Frequency Distributions

The distributions plotted in Fig. 11 would represent a normal distribution as a straight line with approximately a 45° angle. A lesser slope indicates greater kurtosis or a narrower distribution, a greater slope indicates a wider distribution or lesser kurtosis. Skewness is displayed as asymmetry of slope about the centerline.

Cadmium and Zn have generally similar plots except

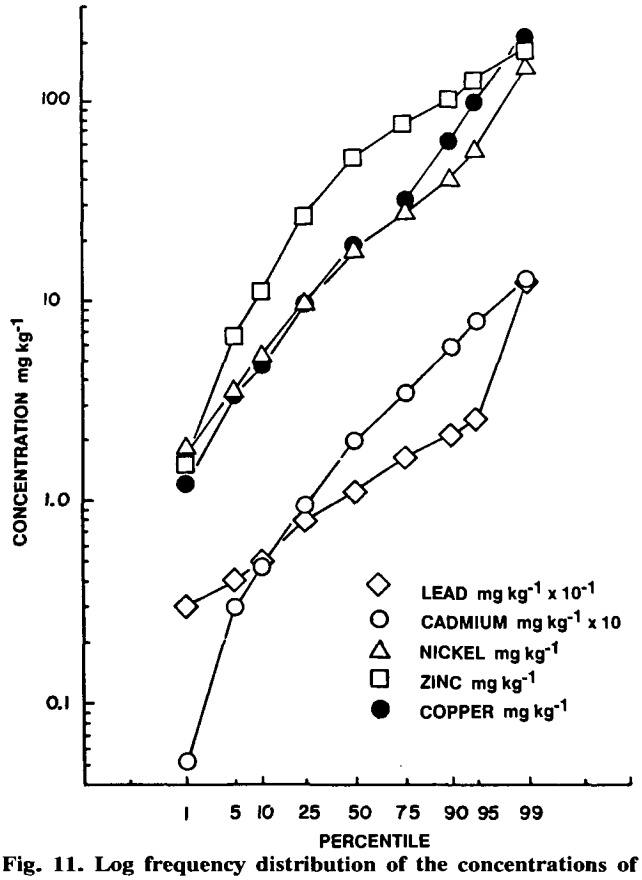

Fig. 11. Log frequency distribution of the concentrations of Pb, Cd, Ni, Zn, and Cu in U.S. soils.

Zn shows more skewness and has a broader distribution below the median than above it. Cadmium distribution is reasonably normal down to the fifth percentile, at which point the distribution narrows. This reflects the clustering of values at the detection limits of the procedure.

Nickel and Cu distribution plots have similar *S* shapes. The increasing slopes toward both upper and lower limits suggest that the distributions cluster at high and low levels. The high values for Ni all represent the serpentine area in California. The high Cu values are restricted to Histosols where fertilizer and pesticide Cu additions have caused fairly uniform high levels. The general narrowing of all distributions except Pb at lower levels reflects the inclusion of a broad area of regionally low values from the Southeast. This in turn is consistent with a decrease in soil microelement concentrations due to weathering (Hodgson, 1963). The fact that Pb shows no such narrowing of distribution at the low end argues that variation of Pb is not controlled by these same factors. It should be emphasized that there is no a priori reason why these distributions should be normal. The sampling distributions are obviously not random and the soil series sampled in the differing regions and soil textures only fortuitously yield a near log-normal distribution. The differences among the curves are, however, significant indicators of the different distribution patterns of the elements.

Factor Analysis

A factor analysis separated the soil analysis data into three subcategories of nonacid mineral, acid mineral, and all organic soils. These groupings were subsequently tested separately (Table 10) because the pH, organic C and CEC varied so widely among these groups that factor analysis of the complete data set simply identified the organic soil and acidic soils as separate groups.

Table 10. Factor analysis for soil elements and associated soil parameters of U.S. surface soils.

Analysis	Factor 1	Factor 2	Factor 3
Nonacid mineral soils			
Pb	0.60	−0.15	0.11
Cd	0.59	0.11	0.61
Zn	0.83	0.22	0.00
Cu	0.86	0.15	0.39
Ni	0.77	0.16	−0.51
pH	0.00	0.84	0.37
OC	0.56	−0.57	0.36
CEC	0.81	−0.11	0.13
Acid mineral soils (pH < 6.5)			
Pb	0.64	−0.07	
Cd	0.80	0.07	
Zn	0.87	0.17	
Cu	0.75	−0.12	
Ni	0.80	0.13	
pH	0.09	0.93	
OC	0.63	−0.02	
CEC	0.84	−0.02	
Histisols			
Pb	0.63	0.40	−0.27
Cd	0.83	−0.07	0.00
Zn	0.35	0.31	0.69
Cu	0.19	0.77	0.11
Ni	0.74	0.06	0.00
pH	−0.02	−0.30	0.71
OC	−0.63	0.72	−0.08
CEC	−0.24	0.72	−0.08

In factor analysis, the various factors represent orthogonal groupings of covarying variables (SAS Inst., 1982). These factors may be though of as unspecified variables that control the variation of several variables. The numbers reflect the strength of the communality between the listed variables and these presumed underlying variables. Correlation (R^2) between any two variables within a factor may be calculated as the product of the two coefficients. Similarly, the total variance explained by all factors for any one element is the sum of the squared values in that row. Table 10 includes only those factor coefficients with values greater than 0.5.

The most striking feature of Table 10 is the almost complete separation of pH into a separate factor (2) for acid and nonacid mineral soils. This negative effect is at least a partial reflection of the pH separation of the populations. Trace elements show a reasonable degree of correlation with CEC and organic C. Thus organic soils show a high degree of correlation among CEC, organic C, and Cu. This corresponds to the known addition of Cu as a fertilizer and pesticide to these soils. Recent evidence shows that increased Cu in organic soils inhibits the decomposition of the organic matter (Mathur and Sanderson, 1980). The covariation of Zn and pH in Factor 3 of Histosols is unexplained.

Subsoils

Table 11 lists the surface and subsoil Cd for those soil sites with more than 1 mg Cd/kg in the surface soil. Subsoil here refers to the horizon immediately subjacent

Table 11. Cadmium concentration in 26 surface and subsurface soil horizons with surface soil Cd ≥ 1.0 mg/kg.

Site, soil series	State	Surface soil	Subsurface	Surface / Subsurface
		— mg Cd/kg dry wt. —		
Mineral soils				
Pancheri	ID	2.0	0.33	6.1
Bath	NY	1.8	0.16	11.0
Mocho	CA	1.7	1.60	1.1
Salinas	CA	1.5	1.10	1.4
Salinas	CA	1.4	1.60	0.88
Salinas	CA	1.4	0.73	1.9
Rocky Ford	CO	1.4	1.50	0.93
Rocky Ford	CO	1.2	1.20	1.0
Mocho	CA	1.1	1.00	1.1
Mocho	CA	1.1	1.30	0.85
Organic soils				
Carlisle	MI	2.0	1.20	1.7
Carlisle	MI	1.8	0.76	2.4
Carlisle	MI	1.8	0.50	2.7
Carlisle	NY	1.6	0.93	1.7
Houghton	MI	1.6	1.10	1.5
Terra Ceia	LA	1.4	0.85	1.6
Carlisle	NY	1.4	0.52	2.7
Palms	MI	1.3	0.40	3.3
Adrian	MI	1.3	0.22	5.9
Adrian	MI	1.2	0.41	2.9
Palms	MI	1.2	0.55	2.2
Palms	Mi	1.1	0.22	5.0
Carlisle	NY	1.1	0.45	2.4
Edwards	NY	1.1	0.49	2.2
Edwards	MI	1.1	0.67	1.6
Adrian	MI	1.1	1.80	0.61

to the tilled layer. It was reasoned that if the ratio of Cd in surface soil/Cd in subsoil were appreciably greater that 1, that anthropogenic contamination of the soil had probably occured. The greater oxidation of surface than subsurface organic C in Histosols would increase this ratio.

Of the 26 soils listed, 16 are organic. Organic soil data are biased upward by virtue of the low bulk density of these soils. On a comparable volume basis, these soils could possibly be half or less than the values reported here. These amounts still represent an accretion of Cd, probably due to heavy fertilizer additions as previously noted. The surface/subsoil ratios of these organic soils are, with two exceptions, greater than 1.5. This is consistent with surface accumulation. These subsurface samples confirmed that the soil Cd decreased to lesser levels at greater depth.

Of the 10 mineral soils, 7 have surface/subsoil ratios less than 1.5, suggestive of strong geologic control of the Cd content rather than surface enrichment. Of these, five are from California and two from Colorado. The California soils are influenced by the Monterrey shales as previously mentioned. The Rocky Ford soils from Colorado are formed in alluvial deposits from the Arkansas River. Presumably the Cd derives from some upstream source in the Rocky Mountains. Shacklette and Boerngen (1984 p. 1–105) have noted that some Colorado soils are rich in Zn, Cd, and Pb, several areas in Colorado have been intensely polluted by fluvial redistribution of Ag mine wastes.

Zinc/Cadmium Ratios. The estimated crustal ratio of Zn to Cd is 270 although ratios as low as 10 to 30 have been noted for black shales (Tourtelot et al., 1964). Table 12 summarizes the geometric mean Zn/Cd ratios by state for the data reported here. The lowest values reported are for Michigan. Soils sampled in this state were organic soils and the low ratio probably reflects the predominate contribution of fertilizer as a source of Cd. New York, Wisconsin, and Oregon also might be expected to have low ratios for the same reason. Nebraska, North Dakota, and South Dakota may have been influenced by Cd from the Pierre shales. Values from Pennsylvania are likely distorted by aerosol contaminations (e.g., from Zn smelters). North Carolina and Kansas are the only other states with ratios less than 200. Five states have ratios greaters than 350. Interestingly, all are from the strongly weathered area along the East Coast indicating that Zn/Cd increases with time of weathering. The reported Cd values are near the detection limit for South Carolina, Virginia, Georgia, and Maryland, and the ratios are consequently subject to large variance.

Table 12. Distribution of geometric mean Zn/Cd ratios by state (states arranged alphabetically within Zn/Cd range).

Geometric mean Zn/Cd ratio range	States
< 100	MI
150–199	FL, ID, KS, NC, ND, NE, NY, SD, WI
200–249	CO, IN, MN, MO, MT, NM, OH, OR, TX
250–299	AR, IA, IL, OK
300–349	AZ, CA, GA, LA, NJ
> 350	AL, MD, ME, PA, WA

CONCLUSIONS

In general, these data show little evidence of significant accumulation of Cd or Pb in cropland soils, although Zn and especially Cu have accumulated from normal agricultural practices. Only a few regions with appreciable natural enrichment in Cd or Pb, or widespread low level contamination with Cd or Pb were identified. The Cd concentration in lettuce and spinach is known to be anomalously high in parts of the Salinas Valley which have soil with anomalous higher soil Cd concentrations. No anomalous crop Pb results were observed in relation to soil Pb concentration.

On the other hand, the original concern about risk from soil Cd noted in the introduction is now understood to be an overstatement. The original estimate of 39 μg Cd/d U.S. dietary Cd is really about 12 μg/d for 70-kg adults (Adams, 1991). The WHO-suggested limit for dietary Cd was 67 to 83 μg/d, not 52 to 71 as often published (Fox, 1988). Polished rice grain is known to become enriched in Cd when rice is grown on Cd-rich soils, but the grain has low levels of Zn, Fe, and Ca. These latter elements normally reduce Cd absorption by humans, and their low levels in polished rice increase the bioavailability of Cd in that grain. Other food sources do not comprise the potential for Cd risk to humans indicated by human health effects which resulted from rice in Japan (Chaney, 1988).

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