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Total Content of Nine Mineral Elements in Fifty Selected Benchmark Soil Profiles of California

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One hundred ninety-five soil horizons from 50 benchmark soil profiles in California were analyzed for total aluminum, magnesium, manganese, nickel, cobalt, copper, iron, molybdenum, and zinc by acid decomposition, resin column separation, and colorimetric methods. Half of the soil series contain low and possibly deficient levels of one or more of the following essential elements: cobalt, copper, molybdenum, manganese, and zinc. Four soil series profiles identified with alkali basins contain relatively high, and probably toxic, levels of molybdenum.

Statistical analyses of the data show that soil series can be grouped on the basis of horizon development, differences between soil profiles or parent material and stratification, or combinations of these controlling influences. In most soils, two distinct groups of elements occur that are negatively correlated between groups and highly correlated positively within groups. Elements which appear most frequently in the same groups together are cobalt, copper, iron, magnesium, and often zinc. Molybdenum is generally negatively correlated with this group of elements.

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Total Content of Nine Mineral Elements in Fifty Selected Benchmark Soil Profiles of California[1,2]

INTRODUCTION

SWAINE'S (1955)[3] EXTENSIVE REVIEW of the literature attests to the great variety of analytical techniques used to characterize the trace element status of soils—both for the total trace element content and for fractions of trace elements, determined by different extractants. The significance of results obtained by diferent techniques—that is, whether by total analysis or by analysis of an extractable fraction—depends upon many variables, such as soil type, parent material, crop, climate, fertilizer, and management practices.

Mitchell (1955, 1963), who has done extensive research on trace elements in soils, concludes that information on total trace element content is exceedingly valuable in indicating excesses or deficiencies. Vink (1963) states that there is a need for continuous research into the productivity of benchmark soils through cooperative efforts of the soil surveyor and soil chemist. The many recent literature references[4] on the subject of trace elements in soils provide evidence of world-wide interest in this phase of soil science.

The senior author studied a case of severe copper deficiency in orchard grapefruit trees of southern California (Bradford and Harding, 1964), where total copper in the soil was as low as 1.6 ppm. This work stimulated the study reported here of the total content of aluminum, magnesium, nickel, cobalt, copper, iron, molybdenum, manganese, and zinc in fifty selected benchmark soil profiles of California.

MATERIALS AND METHODS

Benchmark soil series samples were selected from an extensive file of soil profile samples in the Department of Soils and Plant Nutrition, Berkeley. The samples were accumulated by cooperative efforts of the University of California, College of Agriculture, and the U. S. Department of Agriculture soil survey teams during more than 50 years of soil survey work in California. A detailed discussion of these soil series is given by Storie and Weir (1953). Each profile sample was selected as the most representative of the series in each area and, in most cases, was undisturbed. They represent some of the major agricultural areas of the State.

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[2] This investigation was supported (in part) by Public Health Service Research Grant No. UI 00484 from the National Center for Urban and Industrial Health, and by NSFG 18857.
[3] See "Literature Cited" for citations referred to in the text by author and date.
[4] See "References."

Brief description of soil series[5]

The Aiken soils are members of a fine-textured kaolinitic, mesic family of Andic Palehumults (Reddish-Brown Lateritic soils) formed on rolling to steep terrain from the weathering of andesitic tuff-breccia under a cover of coniferous forest.

The Cajon (Coachella) soils are members of a sandy-textured, mixed mineralogy, nonacid, thermic family of Typic Xeropsamments (Regosols) formed on hummocky, wind-deposited or wind-modified, lake-laid sands around the northwestern margins of a Pleistocene Salton Sea in the Coachella Valley.

The Fresno soils are members of a fine-textured, mixed mineralogy, thermic family of Typic Nadurargids (Solonetz) formed from moderately coarse-textured, granitic alluvium.

The Hanford soils are members of a coarse, loamy-textured, mixed mineralogy, nonacid, thermic family of Typic Xerorthents (Alluvial soils) formed from recently deposited, moderately coarse-textured, granitic alluvium.

The Holland soils are members of a fine, loamy-textured, mixed mineralogy, mesic family of Typic Palehumults (Reddish-Brown Lateritic soils) formed in weathered, granitic rock on rolling-to-steep terrain.

The Hugo soils are members of a fine, loamy-textured, mixed mineralogy, mesic family of Typic Ustochrepts (Regosols) formed on steep, mountainous relief from feldspathic sandstones and shales under dense redwood and Douglas fir forest.

The Imperial soils are members of a fine-textured, mixed, calcareous, thermic family of Typic Torriorthents (Alluvial soils) formed on recent deposits of the lower Colorado River.

The Kettleman soils are members of a fine, loamy-textured, mixed mineralogy, calcareous, thermic family of Typic Xerorthents (Regosols) formed on hilly-to-steep relief on calcareous sandstones and shales under a thin cover of annual grass.

The Lassen soils are members of a mesic family of Vertisols (Grumusols) formed on hilly-to-steep relief from basic igneous rocks.

The Los Osos soils are members of a fine-textured, mixed mineralogy, thermic family of Typic Argixerolls (Prairie, or Brunizem soils) found on rolling-to-steep slopes under grass vegetation and formed from hard, sedimentary rock.

The Maymen soils are members of a loamy-textured, mixed mineralogy, thermic family of Lithic Ustochrepts (Lithosols) formed under chaparral brush on hard sandstones and shales where the relief is steep and mountainous.

The Merced soils are members of a fine-textured, montmorillonitic, calcareous, thermic Typic Haplaquolls (Humic Gley soils) formed from mainly granitic alluvium but with some mixture of sediment from sedimentary rocks.

The Mojave soils included here are members of a fine, loamy, mixed mineralogy, thermic family of Typic Haplargids (Red Desert soils) mainly formed on granitic alluvium.

The Ramona soils are members of a fine, loamy, mixed mineralogy, thermic family of Typic Haploxeralfs (Noncalcic Brown soils). They are formed on gently sloping alluvial fans of granitic alluvium.

The Redding soils are members of a fine-textured, mixed mineralogy, thermic family of Abruptic Durixeralfs (maximal Noncalcic Brown soils) formed from gravelly alluvium derived from mixed rock sources.

The San Joaquin soils are members of a fine-textured, mixed mineralogy,

[5] The authors express appreciation to Dr. Frederick F. Peterson, Assistant Professor of Soil Science, Department of Soils and Plant Nutrition, University of California, Riverside, for the brief description presented here of soil series amended and annotated to show new U. S. 7th Approximation Soil Classification (1965) names.

thermic family of Abruptic Durixeralfs (maximal Noncalcic Brown soils) formed on old, gently sloping fans of granitic alluvium.

The Watsonville soils are members of a fine-textured, montmorillonitic, mesic family of Typic Agrialbolls (Planosols) found on coastal terraces about 100 feet above sea level.

The Yolo soils are members of a fine, silty, mixed mineralogy, thermic family of Entic Xerumbrepts (Alluvial soils) formed from recently deposited, medium-textured alluvium derived from sedimentary rocks.

Samples were analyzed by the method of Bradford, *et al.* (1965). A 0.5-gram soil sample was decomposed with perchloric and hydrofluoric acids. The trace elements were separated and concentrated on a column of a strongly basic anion exchange resin (Dowex 1-X8) by successive elutions, with different volumes of hydrochloric acid of decreasing molarity. Some elements were further separated by organic extraction, and, finally, all elements were determined by conventional colorimetric methods. The entire procedure was considered satisfactory when 100 ± 5 per cent of added trace elements were recovered. A well-equipped spectrographic laboratory was also available for these studies. This method of soil analysis was not used, however, because of the complex spectra produced by the usually large amounts of iron, aluminum, manganese, and titanium in soils.

RESULTS AND DISCUSSION

Table 1 lists the total concentration of aluminum, cobalt, copper, iron, magnesium, molybdenum, manganese, nickel, and zinc in each horizon of 50 California soil profiles identified according to soil series classification, depth of horizon, and geographical location.

These data, for the elements known to be essential for plants and/or animals, are significant when compared to the normal concentration ranges compiled by Mitchell (1955) and the deficiency levels as determined by different investigators listed in table 2.

SOIL SERIES (AND NUMBER)	DEFICIENT MINERAL ELEMENT
Coachella (all) Fresno (1 of 3) Mojave (1 of 2)	Co
Coachella (all) Fresno (1 of 3) Holland (2 of 3) Kettleman (1 of 3) Los Osos (1 of 3)	Cu
Kettleman (1 of 3) Maymen (1 of 3)	Mo
Kettleman (1 of 3)	Mn
Coachella (all) Fresno (1 of 3) Hanford (1 of 2) Kettleman (1 of 3) Ramona (1 of 2)	Zn

Table 2, then, can be compared with the text table (see left column here) which shows the soil series (from table 1) that are considered low or deficient in the listed mineral elements.

Half of the 50 soil profiles (table 1) might be considered adequately supplied with cobalt, copper, molybdenum, manganese, and zinc. Deficiency symptoms in the other half probably affect plants and/or animals that derive their entire food sources from these soils, and might, therefore, be expected to respond to fertilization with one or more of the essential trace elements.

It is apparent that there is no marked association of total essential trace element content with the series designation. However, since mapping soil series depends entirely on macroscopic observations (aided by a hand lens for an estimate of the mineralogy and rock source of the parent material), it is not surprising that trace-element content is not entirely consistent within widely separated samples of the same soil series.

TABLE 1

TOTAL CONTENT OF NINE MINERAL ELEMENTS IN 195 HORIZONS OF FIFTY CALIFORNIA SOIL PROFILES

Soil series, area, depth (inches)	Al	Co	Cu	Fe	Mg	Mo	Mn	Ni	Zn
	per cent	*ppm*	*ppm*	*per cent*	*per cent*	*ppm*	*ppm*	*ppm*	*ppm*
Altamont, El Cajon									
0–8	5.76	11.5	36.0	1.94	0.61	0.91	385	14.7	64
8–30	7.60	12.0	23.0	2.90	0.84	1.59	222	21.0	74
30–36	7.30	16.5	28.0	2.76	1.04	1.59	356	21.1	82
Altamont, Glen Co.									
0–2	7.26	21.0	56.4	4.66	1.32	2.27	388	60.0	131
2–11	8.20	20.5	60.4	4.84	1.17	2.50	477	63.0	114
11–20	8.46	20.0	52.0	4.86	1.42	2.27	500	66.0	111
20–26	8.36	19.0	51.6	4.94	1.42	1.44	413	66.0	111
26–34	6.76	17.5	67.0	4.94	1.47	2.27	444	63.0	122
34+	7.94	25.0	79.0	5.00	1.54	1.59	284	65.0	127
Altamont, Tehama									
0–2	7.10	22.5	65.6	4.42	1.28	1.59	864	74.0	114
2–7	7.00	22.5	74.4	4.46	1.18	1.36	920	72.0	111
7–17	6.20	23.0	68.0	4.36	1.30	1.59	648	71.0	109
17–24	6.16	22.0	66.0	4.08	1.22	1.59	829	74.0	107
24–35	5.46	19.0	54.0	3.85	1.42	1.59	518	89.0	109
35–42	5.60	19.5	56.0	3.70	1.46	2.27	862	104.0	106
Aiken, Placerville									
0–1½	6.14	31.0	69.0	6.85	1.24	1.36	1360	76.0	104
1½–10	7.36	38.0	98.0	7.30	1.26	1.36	1494	82.0	84
10–28	7.46	38.5	104.0	7.50	1.26	1.89	1490	84.0	81
28–36	6.84	42.0	112.0	7.75	1.54	1.36	1000	93.0	80
Aiken, Placerville									
0–2	7.00	20.5	69.4	7.60	0.52	4.66	1040	114.0	93
2–14	6.76	22.0	70.0	8.03	0.54	3.01	1330	125.0	89
14–28	7.90	20.0	78.0	8.50	0.58	3.07	700	129.0	73
28–60	8.40	21.0	81.6	9.06	0.62	2.87	340	144.0	83
Aiken, Tehama Co.									
0–1	1.40	10.0	13.6	1.03	0.12	0.82	2940	42.0	64
0–8	4.20	71.0	88.0	10.30	0.60	1.78	1300	176.0	101
8–17	4.60	73.5	38.0	10.27	0.63	2.50	1920	286.0	98
17–25	4.70	73.5	87.0	10.17	0.58	1.88	2120	316.0	82
25–37	4.34	65.5	80.6	9.43	0.72	1.13	1160	320.0	71
37–49	4.60	62.5	80.0	8.93	1.08	0.63	1140	367.0	68
49–62	4.70	62.5	82.0	8.93	1.80	0.63	1240	338.0	80
62+....rocks	3.10	51.0	46.0	7.13	5.36	0.91	680	294.0	88
Coachella, Coachella Area									
0–10	2.60	6.0	0	1.90	0.80	1.88	440	12.0	38
10–72	3.30	9.5	0	2.67	1.04	2.73	550	18.0	60
Fresno, Bakersfield									
0–5	3.80	12.5	10.4	3.80	1.60	12.84	700	36.0	114
5–13	3.60	15.0	20.2	3.50	1.46	12.61	700	40.0	106
13–36	3.70	9.0	9.0	2.33	0.90	2.91	650	24.0	60
36–53	2.20	8.0	9.0	2.73	0.90	2.97	556	22.0	64
53–65	4.06	8.0	13.6	2.50	0.92	1.36	570	15.0	64
Fresno, Lodi Area									
0–12	4.26	7.0	4.4	1.74	0.54	1.13	500	9.0	42
12–37	4.06	6.5	4.0	1.80	0.58	1.20	480	9.0	41
37–60	3.30	8.0	9.0	2.44	0.78	0.73	515	13.0	48
Fresno, Merced Area									
0–2½	3.50	8.5	12.0	2.40	1.17	0.91	590	27.0	72
2½–5	3.86	9.0	18.0	2.94	1.38	2.16	775	40.0	81
5–9	4.46	12.0	28.2	3.52	1.89	1.88	792	43.0	93
9–17	4.36	15.5	31.6	3.40	1.93	2.16	720	51.0	92
17–26	4.36	14.0	28.4	3.22	2.02	2.04	705	55.0	70
26–33	3.46	15.0	37.6	2.74	2.37	2.16	610	58.0	75
33–56	4.46	15.5	32.0	3.26	1.94	1.13	590	57.0	60

TABLE 1—*Continued*

Soil series, area, depth (inches)	Al	Co	Cu	Fe	Mg	Mo	Mn	Ni	Zn
	per cent	*ppm*	*ppm*	*per cent*	*per cent*	*ppm*	*ppm*	*ppm*	*ppm*
Hanford, Lodi Area									
0-12	4.76	8.0	12.0	2.44	0.64	1.25	540	12.0	55
12-38	4.80	9.5	11.0	2.80	0.74	3.70	515	14.0	51
38-72	4.90	9.0	9.0	2.40	0.71	1.36	441	12.0	51
Hanford, El Cajon									
0-12	4.80	14.5	11.0	4.40	1.33	1.38	950	8.0	76
12-72	4.80	16.5	13.6	4.86	1.42	1.44	1020	8.0	84
Holland, Fresno-Sierra									
0-7	5.26	12.8	7.0	3.44	0.66	2.98	780	10.5	86
7-24	5.26	13.0	6.0	3.68	0.67	3.55	615	10.5	72
24-60	5.16	10.0	3.6	3.48	0.58	2.95	290	9.5	62
60+	5.20	10.0	1.0	3.14	0.50	3.80	245	7.3	58
Holland, Placerville									
0-2½	4.30	11.0	4.6	2.96	1.18	1.77	635	21.0	74
2½-12	4.90	12.0	4.6	3.20	1.42	1.88	745	25.0	74
12-28	4.96	14.0	9.0	3.60	1.60	1.36	631	27.0	74
28-48	5.06	13.0	14.0	3.76	1.34	1.13	360	25.5	60
Holland, Placerville									
0-3	4.56	31.5	34.4	5.40	3.70	1.55	1140	168.0	89
3-14	5.20	40.0	52.0	6.36	4.68	1.55	1320	189.0	120
14-28	4.80	36.0	49.6	5.40	3.80	1.44	1100	183.0	76
28-50	5.00	38.0	82.0	5.36	3.70	1.44	1000	175.0	72
Hugo, Humbolt Co.									
0-1½	2.64	8.0	8.4	1.60	0.54	1.13	2980	23.8	129
0-3	4.50	19.0	31.6	3.46	1.22	1.25	3320	50.5	173
3-13	5.00	20.5	34.4	3.58	1.40	1.55	1320	46.7	123
13-33	4.60	18.0	39.0	3.58	1.38	1.44	950	46.3	139
33-52	5.00	17.5	48.8	4.26	2.02	1.55	575	48.4	133
52-72	4.80	18.5	59.6	4.26	1.02	1.36	670	48.4	130
Hugo, Dixon Area									
0-10	5.20	19.0	64.0	4.26	1.94	1.44	620	48.4	146
10-26	4.80	18.5	60.0	4.56	1.05	1.36	590	48.6	134
26-36	5.00	19.0	62.0	4.56	1.06	1.88	625	53.7	151
Imperial, El Centro									
0-24	4.60	10.0	26.0	3.10	1.87	1.77	565	27.4	100
24-72	3.40	7.0	7.0	1.80	1.21	1.13	370	17.9	55
Imperial, Palo Verde									
0-12	4.10	9.0	24.6	2.70	1.89	1.55	535	25.4	92
12-56	4.50	11.0	24.0	3.10	1.94	1.36	620	29.0	104
56-72	4.50	11.0	24.2	3.10	1.94	1.77	562	27.8	98
Imperial, Brawley									
0-36	5.30	10.0	28.0	3.06	1.82	1.44	535	28.8	101
36-72	5.54	11.0	25.6	3.10	1.81	1.44	535	29.8	104
Kettleman, Mendota									
0-7	4.80	9.0	7.0	2.16	1.14	1.38	365	71.6	63
7-22	4.30	9.0	7.0	2.03	1.24	1.18	375	80.0	60
22-30	3.70	10.0	7.0	1.80	1.20	1.25	290	79.0	51
30 +	4.50	9.0	7.0	2.00	1.30	1.30	320	81.2	52
Kettleman, Bakersfield									
0-16	3.26	4.0	24.0	1.76	0.79	5.80	205	50.0	126
16-28	3.60	8.0	36.0	2.00	0.72	11.50	165	65.0	178
28-36	4.14	6.0	52.0	2.60	0.92	13.90	170	82.0	212
Kettleman, Coalinga									
0-8	4.60	12.5	20.4	2.60	1.19	0.83	520	54.7	73
8-18	4.28	12.0	15.6	2.40	0.98	0.56	500	50.0	67
18-40	4.45	10.0	13.6	2.50	0.96	0.78	405	52.6	50
Lassen, Alturas Area									
0-5	5.76	32.0	54.0	5.16	1.36	0.90	1280	68.8	92
5-12	5.40	32.0	54.0	5.24	1.50	1.13	1220	73.6	90
Lassen, Pixley Area									
0-15	3.50	64.5	50.0	5.50	9.12	1.31	1300	1001	88
15-26	3.30	65.5	43.6	5.50	8.80	1.13	1190	1001	81
26 +	1.20	78.5	14.0	4.54	16.00	0.79	355	1523	61

TABLE 1—*Continued*

Soil series, area, depth (inches)	Al	Co	Cu	Fe	Mg	Mo	Mn	Ni	Zn
	per cent	*ppm*	*ppm*	*per cent*	*per cent*	*ppm*	*ppm*	*ppm*	*ppm*
Los Osos, Lake Co.									
0–8	5.20	25.0	64.4	5.00	1.56	0.79	1380	106.6	124
8–20	5.40	22.0	71.0	5.68	1.38	1.13	730	107.3	111
20–43	5.40	22.5	68.0	6.10	1.56	1.13	570	108.5	107
43–50	5.24	17.5	62.6	5.68	1.68	1.20	550	105.2	110
50 +	5.56	24.0	71.0	5.92	1.77	1.13	650	113.6	129
Los Osos, Santa Barbara									
0–11	6.00	14.5	41.0	4.42	1.12	0.56	500	36.8	125
11–28	5.90	12.5	40.0	4.82	1.13	0.81	504	35.7	130
28–41	6.60	15.5	43.6	5.12	1.16	1.59	500	49.4	149
41–53	6.36	10.5	45.0	6.00	1.18	1.88	330	32.6	160
Los Osos, Tracy Area									
0–14	3.54	6.5	0.56	1.60	0.14	2.15	500	13.6	52
14–31	4.30	5.5	0.56	1.78	0.25	1.13	400	18.9	56
31–67	4.50	8.0	0.56	2.00	0.30	1.59	135	34.2	73
Maymen, Glenn Co.									
0–5	7.00	17.0	58.6	6.34	1.47	1.20	760	75.3	172
5–9	7.90	21.0	75.6	6.00	1.78	1.59	595	71.4	122
Maymen, Glenn Co.									
9 + PM	6.50	24.0	63.4	5.56	1.74	1.25	601	66.6	116
Maymen, Lake Co.									
0–10	6.06	17.0	49.6	4.56	2.06	0.81	840	53.6	105
10–20	8.06	18.0	63.4	5.12	2.34	0.79	800	48.0	114
Maymen, Tehama Co.									
0–1	6.10	26.5	68.4	6.66	1.60	1.13	840	98.0	116
1–7	6.40	28.5	83.8	6.20	1.78	1.13	601	107.0	106
7 +	6.84	26.5	89.0	6.40	2.10	.68	410	107.6	114
Merced, Bakersfield									
0–8	5.24	10.0	29.6	3.62	0.94	9.09	350	21.2	78
8–22	6.04	11.0	30.0	4.00	1.08	4.43	280	25.2	78
22–31	5.06	8.5	18.0	2.92	0.96	4.99	215	19.0	66
31–52	2.94	3.5	7.0	1.30	0.36	1.13	40	6.8	32
Merced, Fresno									
0–4	5.56	12.5	38.4	3.46	1.12	2.47	255	67.8	80
4–12	6.50	9.0	9.0	3.14	1.08	9.77	34	66.8	93
12–46	6.30	11.0	10.0	3.20	1.18	27.50	103	73.2	90
46–56	6.00	6.5	2.5	2.86	1.25	2.27	111	61.0	92
56–70	5.80	9.5	13.6	2.40	1.19	5.11	252	44.2	73
70 +	4.80	8.0	7.0	1.80	1.48	11.50	412	21.0	81
Merced, Merced									
0–5	6.10	4.0	0	2.46	0.90	1.36	40	30.0	120
5–10	6.20	9.0	8.2	2.70	0.84	9.09	95	26.3	79
10–19	6.80	11.0	12.0	2.44	0.79	1.59	193	25.2	65
19–30	6.10	8.0	10.0	2.26	0.88	2.27	211	25.4	73
30 +	5.50	10.0	12.0	2.44	0.78	2.72	572	50.0	62
Mojave, Barstow									
0–3	5.10	4.5	7.0	1.80	0.63	1.59	335	10.1	55
3–10	4.90	4.5	7.0	1.66	0.56	1.32	380	8.2	52
10–20	5.10	2.5	14.0	1.80	0.80	5.80	200	8.8	52
20–30	5.00	7.2	15.0	1.94	0.81	10.07	280	10.5	54
30–60	5.00	2.5	5.6	1.16	0.30	0.91	193	4.2	34
Mojave, Victorville									
0–18	5.56	9.0	18.0	2.46	0.86	5.45	445	18.9	58
18–30	5.46	9.5	17.6	2.44	0.94	4.77	445	21.0	58
30–60	5.17	8.0	17.6	2.66	1.06	1.25	350	21.6	73
Ramona, El Cajon									
0–10	6.70	22.5	43.6	4.16	1.58	4.43	1020	12.6	73
10–20	6.84	22.5	49.6	5.46	1.56	2.45	1040	16.4	73
20–50	6.86	18.0	38.4	4.60	1.28	2.27	860	12.2	60
50–72	6.20	16.0	26.0	5.04	1.54	1.59	864	11.6	64
Ramona, Lodi Area									
0–8	4.56	4.5	11.0	1.66	0.24	0.91	460	14.7	34
8–33	4.76	9.5	15.6	2.60	0.29	0.91	670	24.4	44
33–48	5.40	2.0	13.6	2.40	0.32	5.45	365	21.0	44
48–72	6.00	9.0	14.0	2.66	0.36	8.68	640	27.0	67

TABLE 1—*Continued*

Soil series, area, depth (inches)	Al	Co	Cu	Fe	Mg	Mo	Mn	Ni	Zn
	per cent	*ppm*	*ppm*	*per cent*	*per cent*	*ppm*	*ppm*	*ppm*	*ppm*
Redding, Glenn Co.									
0–7	3.30	9.0	14.0	1.86	0.32	1.14	415	42.0	61
7–14	3.20	9.0	16.6	1.86	0.36	5.45	430	41.0	44
14–23	5.30	10.0	47.0	3.46	0.82	5.11	260	91.0	90
23–25	4.90	25.0	36.0	3.66	1.22	1.32	420	130.0	73
Redding, Tehama Co.									
0–2	3.40	9.0	17.6	1.96	0.32	4.73	350	35.0	46
2–7	3.20	9.0	19.0	2.00	0.32	1.59	350	35.0	46
7–13	3.96	14.0	27.0	2.64	0.57	2.95	350	49.0	43
13–19	4.44	18.0	35.4	3.64	0.79	3.70	350	70.0	58
19–23	4.56	19.5	40.0	4.24	1.16	1.32	370	144.0	77
23–35	4.54	38.0	40.0	3.72	1.17	4.27	576	136.0	63
35–48	4.40	11.0	36.6	3.60	1.17	4.43	760	72.0	62
48–60	4.54	9.5	40.0	3.90	1.22	1.14	380	70.0	66
San Joaquin, Merced									
0–9	4.40	10.0	33.8	2.00	0.57	2.45	270	17.0	52
9–13	4.40	11.0	11.0	1.96	0.51	1.59	320	18.0	43
13–17½	4.42	11.0	11.0	1.96	0.50	2.27	580	20.0	44
17½–20½	4.78	11.5	9.0	2.06	0.49	1.36	550	20.0	44
20½–25	7.30	9.5	11.0	4.20	0.68	1.59	330	37.0	64
25–27	5.40	11.0	14.0	3.20	1.05	1.14	220	24.0	64
27–40	5.04	10.5	18.0	3.80	1.40	2.93	482	29.4	82
40–50	4.66	15.5	16.0	3.24	1.06	2.93	775	24.8	74
San Joaquin, Pixley									
0–16	4.14	10.5	8.6	2.76	0.68	1.77	690	19.0	84
16–24	4.70	11.0	14.0	2.70	0.80	3.22	745	22.2	66
24–34	5.04	12.0	14.6	3.00	1.02	2.93	630	26.0	89
34–66	4.76	12.0	16.0	3.72	1.20	1.36	730	23.8	81
Staten, orig. loam									
0–12	1.30	6.0	7.6	2.16	0.72	3.55	660	22.8	28
12–40	1.36	3.5	11.0	1.04	0.54	1.32	370	19.0	28
Watsonville, Santa Barbara									
0–8	3.20	10.5	7.6	1.20	0.28	0.79	630	27.0	32
8–18	3.06	10.5	4.4	1.24	0.24	0.44	710	30.6	33
18–24	3.30	6.0	1.6	1.00	0.16	1.36	370	16.9	31
24–37	4.06	5.0	1.6	2.90	0.60	2.50	140	49.4	61
37–50	4.70	2.5	12.4	2.84	0.70	1.89	90	39.6	66
50–70	4.40	4.5	13.0	2.60	0.62	1.77	100	36.4	73
Watsonville, Santa Cruz									
0–10	3.76	12.0	12.0	1.60	0.22	1.14	700	21.0	49
10–20	3.90	13.0	11.0	1.64	0.22	1.59	840	23.8	48
20–24	3.76	34.5	12.0	2.50	0.26	1.78	1490	25.2	52
24–37	4.74	10.0	18.0	2.60	0.46	1.14	160	33.6	72
37–50	4.84	4.5	13.0	2.44	0.46	1.44	240	34.7	70
Watsonville, Santa Cruz									
0–19	4.14	8.5	2.0	2.16	0.30	1.36	470	23.2	33
19–22	4.44	7.0	2.0	3.04	0.41	0.68	292	41.0	37
22–28	4.06	7.0	4.4	1.68	0.26	0.22	485	16.8	31
28–40	4.76	11.0	7.6	2.12	0.30	0.91	180	35.8	32
Yolo, Dixon Area									
0–15	5.50	22.5	36.0	3.76	2.36	0.82	712	227.0	96
15–72	5.10	16.0	36.6	3.60	2.51	2.39	325	227.0	40
Yolo, Dixon									
0–15	5.20	23.0	39.0	3.60	2.56	2.50	482	256.0	48
15–72	5.20	21.0	38.4	3.66	2.49	2.27	410	232.0	94
Yolo, Tehama Co.									
0–11	6.06	25.5	54.0	4.24	2.44	2.04	675	183.0	76
11–34	6.26	27.0	55.0	4.44	2.63	1.87	760	200.0	69
34–68	6.00	23.0	50.0	4.20	3.00	1.59	510	200.0	59

TABLE 2

NORMAL TOTAL AND DEFICIENT CONCENTRATIONS OF CERTAIN ESSENTIAL TRACE ELEMENTS IN SOIL AS REPORTED IN THE LITERATURE

Element	Normal concentration		Deficient concentration	
	Total	Reference	Total	Reference
	ppm		*ppm*	
Co.......	1.0–40	Mitchell (1955)	<4–5	Harvey (1937), Patterson (1937), Rigg (1940), Russell (1938), Stewart, *et al.* (1941), Walsh, *et al.* (1956), Kubota (1964)
Cu.......	2.0–100	Mitchell (1955)	<12	Bould, *et al.* (1953), Bradford and Harding (1964), Knott (1933), Purvis and Ragg (1962)
Mo.......	0.2–5	Mitchell (1955)	<1	Barshad (1951), Robinson, *et al.* (1951), Walsh, *et al.* (1952)
Mn.......	200.0–3,000	Mitchell (1955)	<200	Mitchell (1955), Swaine (1955)
Zn.......	10.0–300	Mitchell (1955)	<80	Thorne, *et al.* (1942) (see footnote *)

* Eighty per cent of 42 soils analyzed for total and extractable Zn showed plant response to added Zn where total Zn was less than 80 ppm. From Ph.D. thesis of John Trierweiler, Department of Agronomy, Colorado State University, Fort Collins, Colorado. Thesis in process of publication.

TABLE 3

GROUPING OF SOIL PROFILES ACCORDING TO PARENT MATERIAL AND TRACE ELEMENT CONTENT IN UPPER 20 INCHES OF SOIL

Parent material and soil profile	Number of soil profiles containing:				
	Zn		Cu		Deficient trace elements
	>80 ppm	<80 ppm	>12 ppm	<12 ppm	
Granitic alluvium:					
Coachella..................................		1		1	
Fresno (alkali)..............................	2	1	2	1	
Hanford....................................		2		2	
Ramona....................................		2	2		
San Joaquin................................	1*	1	2		
Mojave.....................................		2	1	1	1-Co
Granitic rock:					
Holland....................................	2	1	1	2	
Mixed alluvium:					
Imperial (recent)...........................	3		3		
Merced (young).............................	2	1	2	1	2-Mn
Redding (very old)..........................		2	2		
Watsonville (old)............................		3		3	2-Mo
Yolo (recent)...............................	1	2	3		
Basic igneous rock:					
Aiken......................................	3		3		
Lassen.....................................	2		2		
Sedimentary rock:					
Altamont...................................	2	1	3		
Hugo......................................	2		2		
Los Osos...................................	2		2		1-Mo
Kettleman..................................	1	2	2	1	1-Co, 1-Mo
Maymen....................................	3		3		1-Mo
Peat soil....................................		1		1	1-Co

* May not be pure granitic alluvium.

Table 3 shows the grouping of soil profiles according to parent material, their zinc and copper content, and other low trace-element values. Soils formed from granitic alluvium and granite rock usually can be expected to be low in zinc, copper, or both. Two old soils on mixed alluvium are low in zinc; one is low in copper. Soils formed from sedimentary rocks are generally well supplied with trace elements, but may vary considerably depending on the sediment. The two basic igneous rock soils show no low values as would be expected from this kind of rock. The peat soil is deficient in zinc, copper, and cobalt. In general, the distribution of trace-element content is reasonably consistent within groupings based on soil parent material. This agrees with the work of Archer (1963). Where anomalies exist, the availability of chemical analysis of benchmark soil profiles may lead to the identification of a previously unrecognized soil type as discussed by Taylor, *et al.* (1956).

The Fresno and Kettleman soils from near Bakersfield and the Merced soil from Fresno are all alkali basin soils and contain relatively high, and probably toxic, concentrations of molybdenum. The Mojave soil, an unleached desert soil from Barstow, is also high in molybdenum.

Table 4 shows several highly significant relationships between the total contents in soils of several pairs of elements. Considering the diverse nature of the soil profiles and parent material, some of these relations are notable. Both copper and cobalt tend to increase linearly with increasing iron content. Magnesium content tends to vary inversely with molybdenum, although most soils are relatively low in both molybdenum and magnesium. The highest nickel and magnesium levels are associated with a serpentine soil. In most other soils, magnesium is low, and nickel varies over a wide range.

Table 5 shows the within-group and between-group correlations of groups of elements for several soil series. The data for each series in table 5 were prepared by first arranging the larger values of r into a matrix table (omitting decimals), and then, from the patterns evolved, the elements were separated into groups (labeled A, B, and C) and the within-group mean correlation coefficient ($\bar{r}$) and the between-group values of $\bar{r}$ were calculated. It is evident from table 5 that, in most soils, there are two distinct groups of elements which are negatively correlated between groups and highly correlated positively within groups of elements. In some cases, a third group of elements (C) has correlation coefficients that are intermediate between groups A and B.

The original data in table 1 suggest that the source of these coefficients for the various soil series are due mainly to: horizon development in the Redding, San Joaquin, and Watsonville series; the parent material of different soil profiles in the Altamont, Aiken, Holland, Kettleman and Ramona series; parent material and stratification in the Yolo, Merced, and Imperial series; and parent material and profile development in the Fresno, Hugo, Los Osos, and Mojave series.

The elements which appear most frequently in the same groups in the matrix tables are cobalt, copper, iron, and magnesium, and usually zinc. Essentially the same elements have high correlation coefficients based on analyses of all profiles as listed in table 4. This appears to be primarily a parent-material effect. Molybdenum is generally negatively correlated with this group of elements.

TABLE 4

ELEMENT CORRELATIONS BASED ON ANALYSIS OF 195 HORIZONS OF 50 BENCHMARK SOIL PROFILES FROM CALIFORNIA

	Al	Co	Cu	Fe	Mg	Mo	Mn	Ni	Zn
Al	1.00	0.077 NS	0.52***	0.45***	−0.11 NS	0.029 NS	−0.03 NS	−0.78***	0.38***
Co		1.000	0.63***	0.78***	0.56***	−0.170 NS	0.49***	0.68***	0.20**
Cu			1.00	0.82***	0.20*	−0.140 NS	0.34***	0.25**	0.53***
Fe				1.00	0.25**	−0.120 NS	0.41***	0.33***	0.42***
Mg					1.00	−0.920***	0.11 NS	0.84***	0.15 NS
Mo						1.000	−0.20*	−0.29**	0.13 NS
Mn							1.00	0.15 NS	0.24*
Ni								1.00	0.10 NS
Zn									1.00

* Significant at the 5 per cent (0.19) level.
** Significant at the 1 per cent (0.25) level.
*** Significant at the 0.1 per cent (0.32) level.
NS = Not significant.

TABLE 5

WITHIN- AND BETWEEN-GROUP CORRELATION OF GROUPS OF ELEMENTS FOR SEVERAL SOIL SERIES

Yolo Series

Trace element and group		Group A					Group C		Group B	
		Al	Fe	Cu	Co	Mn	Mg	Zn	Mo	Ni
A	Al	..	99	93	81	75	39	15	−36	−86
	Fe		..	96	77	69	42	10	−27	−87
	Cu			..	76	57	43	−24	−27	−84
	Co				..	85	14	34	−27	−48
	Mn	$\bar{r}$ = .81				..	−14	47	−62	−51
C	Mg						..	−41	12	−26
	Zn							..	57	−16
B	Mo								..	27
	Ni									..
									$\bar{r}$ = .27	

Between A–B, $\bar{r}$ = −.53; between Ni −A, $\bar{r}$ = .71.

Watsonville Series

Trace element and group		Group A						Group B	
		Mg	Ni	Al	Fe	Zn	Mo	Co	Mn
A	Mg	..	80	63	79	75	55	−45	−63
	Ni		..	51	76	51	43	−31	−54
	Al			..	77	56	23	−28	−57
	Fe				..	63	49	−69	−35
	Zn					..	64	−12	−31
	Mo	$\bar{r}$ = .61					..	34	−97
B	Co							..	89
	Mn								..

Between A-B, $\bar{r}$ = − .41.

TABLE 5—*Continued*

Holland Series

Trace element and group		Group A							Group B	
		Co	Cu	Fe	Mg	Mn	Ni	Zn	Mo	Al
A	Co	..	94	97	97	87	85	62	−52	−11
	Cu		..	87	88	74	87	42	−52	−72
	Fe			..	96	84	79	68	−47	−12
	Mg				..	89	81	67	−65	−23
	Mn		$\bar{r}$ = .79			..	68	82	−51	−24
	Ni						..	47	−46	46
	Zn							..	−29	−62
B	Mo								..	52
	Al									..

Between A-B, $\bar{r}$ = −.42.

Los Osos Series

Trace element and group		Group A					Group C			Group B
		Co	Cu	Mg	Fe	Ni	Zn	Al	Mn	Mo
A	Co	..	92	89	78	93	50	40	72	−49
	Cu		..	98	94	88	69	60	57	−45
	Mg			..	95	84	73	64	52	−48
	Fe				..	71	84	78	35	−32
	Ni	$\bar{r}$ = .88				..	32	21	−60	−39
C	Zn						..	95	23	−24
	Al							..	57	−30
	Mn						$\bar{r}$ = .58		..	−45
B	Mo									..

Between A-C, $\bar{r}$ = .56; between A-B, $\bar{r}$ = −.43; between C-B, $\bar{r}$ = .−33; AC combined $\bar{r}$ = .72; between AC-B, $\bar{r}$ = −.39.

Hanford Series

Trace element and group		Group A						Group B		
		Co	Fe	Mg	Mn	Zn	Cu	Mo	Ni	Al
A	Co	..	99	99	97	96	58	−24	−89	−14
	Fe		..	99	99	97	62	−23	−89	−25
	Mg			..	98	97	54	−29	−92	−16
	Mn				..	99	66	−33	−93	−34
	Zn		$\bar{r}$ = .86			..	67	−40	−94	−28
	Cu						..	−92	−47	−74
B	Mo							..	63	−11
	Ni								..	13
	Al									..
									$\bar{r}$ = .22	

Between A-B, $\bar{r}$ = −.50.

TABLE 5—*Continued*

Ramona Series

Trace element and group		Group A							Group B	
		Al	Cu	Fe	Mg	Mn	Zn	Co	Mo	Ni
A	Al	..	86	87	86	81	90	84	23	−43
	Cu		..	87	90	91	76	94	−15	−57
	Fe			..	95	88	79	89	−19	−56
	Mg				..	90	79	92	−18	−72
	Mn					..	84	99	−17	−48
	Zn	$\bar{r}$ = .87					..	84	36	−21
	Co							..	−16	−54
B	Mo								..	53
	Ni								$\bar{r}$ = .53	

Between A–B, $\bar{r}$ = −.27.

Altamont Series

Trace element and group		Group A						Group B		
		Co	Cu	Zn	Fe	Mg	Ni	Mn	Mo	Al
A	Co	..	87	82	76	72	71	49	24	15
	Cu		..	81	76	70	70	51	19	21
	Zn			..	93	86	71	24	56	25
	Fe				..	82	63	18	53	48
	Mg					..	81	22	52	15
	Ni		$\bar{r}$ = .77				..	65	40	−23
B	Mn							..	57	−42
	Mo							$\bar{r}$ = .14	..	28
	Al									..

Between A–B, $\bar{r}$ = 32.8.

San Joaquin Series

Trace element and group		Group A			Group C			Group B		
		Al	Ni	Fe	Mg	Cu	Zn	Mo	Mn	Co
A	Al	..	90	67	80	40	42	−19	−50	−36
	Ni		..	86	41	37	35	13	−26	−20
	Fe	$\bar{r}$ = .81		..	71	57	66	54	−58	−50
C	Mg				..	81	75	32	15	28
	Cu					..	55	50	19	40
	Zn				$\bar{r}$ = .74		..	37	42	17
B	Mo							..	53	36
	Mn								..	54
	Co							$\bar{r}$ = .48		..

Between B–C, $\bar{r}$ = .31; betweenA–B, $\bar{r}$ = −.21; between A–C, $\bar{r}$ = .52.

TABLE 5—*Continued*

Fresno Series

Trace element and group		Group A					Group B	
		Co	Cu	Mg	Fe	Zn	Mn	Mo
A	Co	..	87	91	77	63	55	34
	Cu		..	94	60	41	52	86
	Mg			..	75	60	64	15
	Fe				..	89	78	56
	Zn		$\bar{r}$ = .74			..	81	75
B	Mn						..	35
	Mo							

AB (combined), $\bar{r}$ = .65.

Redding Series

Trace element and group		Group A					
		Al	Cu	Fe	Mg	Ni	Zn
A	Al	..	96	89	83	76	84
	Cu		..	94	87	75	76
	Fe			..	95	82	70
	Mg				..	82	64
	Ni					..	71
	Zn			$\bar{r}$ = .82			..

Aiken Series

Trace element and group		Group A		Group B	
		Al	Mo	Mg	Co
A	Al	..	51	−18	−91
	Mo		..	−68	−58
B	Mg			..	93
	Co				..

Between A–B, $\bar{r}$ = −.59.

Hugo Series

Trace element and group		Group A				Group B	
		Cu	Fe	Al	Mo	Mn	Zn
A	Cu	..	93	57	30	−73	−18
	Fe		..	54	41	−72	−22
	Al			..	54	−63	−41
	Mo	$\bar{r}$ = .55			..	−46	−15
B	Mn					..	70
	Zn						..

Between A–B, $\bar{r}$ = −.44.

TABLE 5—*Continued*

Kettleman Series

Trace element and group		Group A			Group B			
		Cu	Zn	Mo	Co	Mn	Mg	Al
A	Cu	..	96	92	−48	−57	−69	36
	Zn		..	99	−62	−74	−71	−47
	Mo	$\bar{r}$ = .96		..	−65	−81	−67	−48
B	Co				..	85	51	61
	Mn					..	48	67
	Mg						..	54
	Al				$\bar{r}$ = .61			..

Between A–B, $\bar{r}$ = −.60.

Maymen Series

Trace element and group		Group A					Group B	
		Co	Cu	Ni	Fe	Mo	Mn	Zn
A	Co	..	78	85	62	50	−55	−44
	Cu		..	79	64	23	−80	−26
	Ni			..	82	56	−53	−65
	Fe		$\bar{r}$ = .61		..	32	−38	36
	Mo					..	−34	31
B	Mn						..	14
	Zn							..

Between A–B, $\bar{r}$ = .46.

Mojave Series

Trace element	Co	Cu	Fe	Mg	Ni	Zn	Al
Co	..	79	87	74	90	68	73
Cu		..	89	92	84	70	71
Fe			..	94	97	91	71
Mg				..	87	90	57
Ni					..	83	78
Zn						..	39
Al							..

$\bar{r}$ (without Al) = .85; $\bar{r}$ (with Al) = .79.

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