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TRACE ELEMENTS IN SOIL PROFILES OF ISRAEL: THE SOILS OF THE MEDITERRANEAN ZONE

by

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TRACE ELEMENTS IN SOIL PROFILES OF ISRAEL: THE SOILS OF THE DESERT ZONE

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TRACE ELEMENTS IN SOIL PROFILES OF ISRAEL:

I. THE SOILS OF THE MEDITERRANEAN ZONE

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The important role played by certain trace elements in the development of crops has directed attention toward evaluation of soils with regard to the content and availability of trace elements in them. Comprehensive reviews on this topic have been published by Swaine (13) and by Vinogradov (14). Various investigations have dealt with the sources of trace elements in the soil, the type of compounds in which they occur, and their distribution in the soil (3, 4, 7, 8, 12, 14). A number of trace elements studies were carried out on Israel soils (5, 6, 9). The present study is concerned with the distribution of manganese, zinc, copper, cobalt and boron in profiles of soil types which developed in different climatic zones in Israel, and with the degree of their accumulation in the soils during weathering and soil formation.

Climatic conditions ranging from humid to extreme desert climate prevail in Israel. The parent material of the soils used for this study consisted of various types of bedrock, and sediments of fluvial and aeolian origin. As a result of these two dominant soil forming factors, different soil types were developed. The soils were divided as belonging to soils of the Mediterranean or the desert zone. In this paper data are presented on trace elements in soil types formed under Mediterranean climatic conditions, i.e., characterized by short, cool, rainy winters and long, hot, dry summers.

MATERIALS AND METHODS

SOILS

The soils were divided into four groups (I-IV) according to the nature of their parent material. A short description of the soil properties follows, with the profile location indicated in parentheses:*

* A more complete description of the properties and origin of the various soil types can be found elsewhere (11).

I *Soils developed from bedrock*

1. *Terra rossa:* Formed from hard limestone; clay texture; noncalcareous (Eilon, Galilee). 2. *Mediterranean brown forest soil:* Formed from "Nari" (a semi-hard calcareous crust formed on chalk); clay texture; moderate lime content (Mitzpeh Massua, Judean Hills). 3. *Rendzina of mountains:* Formed from chalk; texture – clay loam; highly calcareous (Adụlam, Judea). 4. *Brown basaltic soil:* Formed from basalt rock; clay texture; noncalcareous (Kfar Masar, Galilee). 5. *Rendzina of valleys:* Formed from "Lisan Marl"; clay texture; calcareous (Beit Zera, Jordan Valley).

II *Soils formed from clay alluvium*

6. *Brown alluvial soil (Vertisol):* Formed from old clay alluvium; moderate lime content (Afula, Esdraelon Valley). 7. *Alluvial soil:* Formed from recent clay-loam alluvium; moderate lime content (Bet Dagan, Coastal Plain). 8. *Brown steppe soil:* Formed from old clay alluvium; calcareous (Kiryat Gat, Shephela). 9. *Colluvial-alluvial soil:* Formed from clay alluvium; calcareous (Kfar Zakharia, Judea).

III *Soils formed from sandstone and sand dunes*

10. *Brown-red sandy soil:* Formed from calcareous sandstone-"Kurkar"; calcareous (Rehovot, Coastal Plain). 11. *Brown-red degrading sandy soil:* Formed from sand dunes; noncalcareous (Yashresh, Coastal Plain). 12. *Coastal sand dunes:* Moderate lime content (Rishon L'Zion, Coastal Plain).

IV *Soils formed from swamp plant residues*

13. *Peat soil:* Low-moor type; formed mainly from papyrus; acid reaction (Hula Valley, Galilee).

METHODS

The total contents of manganese, copper, cobalt and zinc were determined by wet digestion in HF and $HClO_3$ and drying by evaporation. The residue was dissolved in HCl and the resulting solution analyzed for these elements using a Perkin Elmer Model 303 atomic absorption spectrometer. Total boron was determined after fusion in Na_2CO_3 and soluble boron by extraction in boiling water with the colorimetric technique according to Berger and Truog (1). All results were calculated on oven dry weight basis.

RESULTS AND DISCUSSION

TRACE ELEMENTS IN THE SOILS

Manganese. High concentrations of manganese were found in brown basaltic soils (578-1470 ppm) as well as in terra rossa soils and Mediterranean brown forest soils formed from hard and semi-hard limestone, respectivley (534-1380 ppm). The manganese content of rendzina soils formed on soft carbonate rocks – chalk and marl, was much lower (82-455 ppm); calcium carbonate with its generally low content of trace elements is a major constituent of these soils (Tables 1, 6). High manganese levels (637-903 ppm) were also found in soils formed from clay alluvium whose

Table 1

Trace elements in soil profiles developed on bedrock

Soil No.	Soil	Horizon depth, cm	Concentration, ppm Mn	Zn	Cu	Co	B Total	B H.W. soluble
1	Terra Rossa	0- 19	791	142	45	21	72	1.2
		19- 57	775	114	38	15	59	1.1
		57- 95 (Soil and disintegrated rock)	492	110	33	15	53	1.0
2	Mediterranean Brown Forest Soil	0- 14	804	109	28	14	45	1.1
		14- 32	725	106	29	11	49	1.0
		32- 58	638	87	25	10	48	0.9
		Rock	50	45	20	1.3	3.1	
3	Rendzina of Mountains	0- 33	262	82	40	4.2	34	1.0
		33- 55	248	70	35	3.0	31	0.8
		55- 72	150	72	32	2.2	21	0.5
		Rock	58	59	20	0.6	0.9	
4	Brown Basaltic Soil	0- 26	688	136	55	25	56	1.1
		26- 42	594	125	57	19	55	1.0
		42- 51	578	101	49	26	40	0.8
		Rock	1080	129	35	27	3.2	
5	Rendzina of Valleys	0- 29	455	161	41	13	66	0.3
		29- 51	405	169	29	13	67	0.3
		51-114	400	162	26	14	53	0.3
		114-178	364	152	32	11	48	0.3
		178-197	328	148	30	10	51	0.2

Table 2

Trace elements in soil profiles developed on clay alluvial material

Soil No.	Soil	Horizon depth, cm	Concentration, ppm Mn	Zn	Cu	Co	B Total	B H.W. soluble
6	Brown Alluvial Soil (Vertisol)	0- 16	779	100	37	19	27	0.2
		16- 42	823	95	36	17	26	0.1
		42- 78	872	94	37	15	28	0.2
		78-109	842	90	29	14	26	0.3
		109-143	795	80	31	11	26	0.5
		143-160	750	80	31	11	25	0.4
7	Alluvial Soil	0- 24	903	63	18	11	26	0.3
		24- 53	872	57	18	10	29	0.4
		53- 86	872	58	17	11	27	0.3
		86-121	865	61	18	12	21	<0.1
		121-148	817	62	15	11	25	0.2
		148-173	855	50	15	10	18	<0.1
8	Brown Steppe Soil	0- 22	740	76	29	7.6	39	0.4
		22- 48	733	70	23	7.3	38	0.5
		48- 69	724	69	23	8.4	40	0.4
		69-113	708	69	23	8.9	31	0.3
		113-145	710	68	24	8.6	30	0.2
9	Colluvial-Alluvial Soil	0- 35	704	53	15	11	39	1.6
		35- 68	660	48	11	9.6	30	1.4
		68-126	637	24	8.0	6.3	26	1.2
		126-185	663	26	4.6	8.6	24	1.3

origin is mainly from mountain soils formed on limestone (Table 2). The manganese content of sandy soils formed from calcareous sandstone or from sand dunes was quite low (34-331 ppm). The lowest levels of Mn were found in peat – 62-93 ppm (Tables 3, 4).

Zinc. The highest zinc contents (72-290 ppm) were found in soils formed from carbonate rocks. Lower concentrations were found in basaltic soils (80-126 ppm), in soils formed from clay alluvium (24-100 ppm) and in peat (41-82 ppm). Soils formed from calcareous sandstone and from sand dunes have a low zinc content (21-39 ppm).

Copper. Moderate to high copper contents (25-61 ppm) are characteristic of soils formed from carbonate rocks and from basalt. Low to moderate values were found for alluvial clay soils (8-37 ppm); and low values for peat (10-15 ppm) and sandy soils (4.7-10 ppm).

Table 3

Trace elements in soil profiles developed on sandstone and sand dunes

Soil No.	Soil	Horizon depth, cm	Concentration, ppm Mn	Zn	Cu	Co	B Total	B H.W. soluble
10	Brown-Red Sandy Soil	0- 27	331	34	5.7	1.8	29	0.3
		27- 39	312	34	4.8	1.7	20	0.3
		39- 53	306	29	4.8	1.7	18	0.2
		Sandstone "Kurkar"	125	16	2.4	0.8	0.4	
11	Brown-Red Degrading Sandy Soil	0- 19	201	39	10	2.9	27	0.9
		19- 33	194	38	8.6	2.4	17	0.8
		33- 51	146	38	8.4	2.3	13	0.8
		51- 66	120	29	8.0	2.1	21	0.9
		66-149	137	34	8.4	2.2	24	0.9
		149-178	132	36	7.4	2.1	20	0.8
		178-213	67	31	6.9	2.0	16	0.4
		213-264	34	21	4.7	1.8	12	<0.1
12	Coastal Sand Dunes	0- 50	48	16	1.9	<1.0	33	0.2
		0- 50	48	18	4.2	<1.0	30	0.1

Table 4

Trace elements in a peat soil

Soil No.	Layer depth, cm	Concentration, ppm Mn	Zn	Cu	Co	B Total	B H.W. soluble
13	0- 30	68	82	11	3.7	96	1.8
	30- 60	93	68	12	1.9	107	3.2
	60- 90	90	41	14	1.7	84	2.4
	90-120	62	60	13	3.5	127	2.2
	120-150	80	59	11	3.1	78	1.8
	150-180	87	54	10	3.0	104	3.5
	180-210	67	57	15	3.8	108	2.6

Cobalt. Soils formed from limestone and basalt have a relatively high cobalt content (15-30 ppm). The highly calcareous soils of chalky-marl origin are appreciably poorer in cobalt (3.2-4.6 ppm). The clay alluvial soils generally are intermediate in cobalt content (7-19 ppm). The soils with the lowest cobalt content (1.7-3.8 ppm) are the sandy soils and peat (Tables 1-4).

Boron. The soils containing the highest amount of boron are peat soils and those formed from limestone, marl (Lisan marl) and basalt (27-78 ppm). Soils of chalk and marl origin and sandy soils contain 12-29 ppm. In most of the mineral soils the amount of boron soluble in hot water is less than 1 ppm, while peat contains 1.8-3.5 ppm of soluble boron. The water soluble boron represents 0.4-5.4% of the total boron in the various soils.

From the above data the various soil types can be classified according to their trace element content. Among the soils formed from carbonate rocks, the terra rossa has the highest values of Mn, Zn, Co, B and at times also Cu. In the Mediterranean brown forest soils high concentrations of Mn and B and sometimes also of Zn are found. The rendzina soils have only a high content of Cu and sometimes also of Zn. The basaltic soils have high concentrations of Mn and Co and at times also B. The group of soils developed from clay alluvium is characterized by a high content of Mn only. The sandy soils and peat have low or very low concentrations of all the trace elements with the exception of boron.

THE DISTRIBUTION OF TRACE ELEMENTS IN THE SOIL PROFILES AND EFFECT OF SOIL PROPERTIES ON THEIR CONCENTRATION

In the profiles of most of the soils it is the A horizon that has the highest concentrations of Mn, Zn and Cu and in some cases also of Co (Tables 1-4). This higher content of trace elements is, to a large extent, the result of their transport from deeper layers by the action of plants and the concentration of their residues in this horizon.

The concentration of certain trace elements in soil groups of similar origin has been found to be in correlation with their clay content. A positive correlation was found in the profiles of the alluvial clay soils between the concentration of Mn, Zn, Cu, Co and B, and the clay content. In the group of soils formed from chalk and marl a positive correlation was found between the concentration of Mn, Co and Zn and clay content; and in the soil group formed from limestone a similar correlation was found for Mn and Co (Table 5). In most of these cases the correlation is significant at the 1% level. In the soil group formed from sandstone and sand dunes, no correlation was found between trace element concentration and clay content. It should be noted that the relationships between trace element concentration, (particularly of Mn and Co) and clay content differ among the various soil groups. The difference is particularly pronounced when soils formed from limestone (terra rossas and Mediterranean brown forest soils) and those

Table 5

Correlations between trace element content and clay content in profiles of soil groups of various origins

Groups of soils	Correlation coefficients				
	Mn	Zn	Cu	Co	B
Soils developed on limestone	0.96**	0.38	0.25	0.64*	0.29
Soils developed on chalk and marl	0.82**	0.61**	0.33	0.96**	-0.15
Soils developed on alluvial clay	0.87**	0.82**	0.97**	0.61*	0.67**
Soils developed on sandstone and sand dunes	0.09		0.33	0.03	0.23

*Significant at the 5% level
**Significant at the 1% level

formed from chalk and marl (rendzinas) are compared. The average ratios of Mn content in mg per gram of clay are three times higher in the former group (1.5 and 1.7, respectively) than in the rendzina soils (0.56). The ratio of mg Co per gram of clay in the first group is twice (0.026 and 0.023, respectively) that in the rendzinas (0.012). In the rendzina soils calcite comprises a large percentage of the clay fraction (2). The calcite can essentially be viewed as particles of the clay fraction size formed mainly by disintegration of the soft carbonate parent rock which is, as mentioned above, relatively poor in trace elements.

TRACE ELEMENT CONTENT IN THE PARENT MATERIAL AND THE SOIL

The relation between trace element content of the parent material and the soil formed from it was investigated in five soil types formed from hard limestone, semi-hard limestone, chalky marl, basalt and calcareous sandstone*. The results are presented in Table 6. The data refer to the solum of the profile.

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* The soils are from Galilee, except for soils No. 2 and 3 (Table 6) which are from the Judean Hills. A short description of these soil types is given under "Materials and Methods".

Table 6

Trace elements in solum and parent rock

Soil No.	Soil type	Locality	Parent material	Solum depth cm	$CaCO_3$ in soil %	Concentration, ppm									
						Mn		Zn		Cu		Co		B	
						Rock	Soil	Rock	Soil	Rock	Soil	Rock	Soil	Rock	Soil
1a	Terra	Yehiam	Hard limestone	0-15	Traces	44	1190	35	132	11	31	0.7	23	1.0	73
1b	Rossa	Har Biria	Hard limestone & chalk	0-15	2.2	49	1100	55	290	16	60	0.4	18	1.6	58
1c		Har Knaan, a	Hard limestone	0-10	Traces	57	1230	58	260	12	61	0.5	18	2.2	74
1d		Har Knaan, b	Hard limestone	0-20	Traces	49	1050	62	230	14	46	0.4	22	1.4	40
1e		Goren	Hard limestone	0-30	Traces	29	1380	50	108	12	31	0.6	15	1.3	50
2	Mediterranean	Mizpe Massua	"Nari" (Calc. crust)	0-58	6.9	50	705	45	98	20	26	1.3	11	3.1	47
2a	Brown Forest	Al Ghabisiya	"Nari" (Calc. crust)	0-15	19	65	993	80	114	16	27	1.2	16	1.2	49
2b	Soil	Har Biria	Semi-hard limestone & chalk	0-25	43	80	534	56	182	15	35	1.6	9.3	1.8	48
2c		Ein Zetim	Semi-hard limestone	0-30	17	55	844	39	246	22	40	1.2	11	1.6	33
2d		Har Addir	Semi-hard dolomite	0-45	19	52	637	54	134	15	29	1.0	11	1.0	68
2e		Yas'ur	"Nari" (Calc. crust)	0-30	1.5	85	972	40	134	12	25	1.2	10	1.8	42
3	Rendzina of	Adullam	Chalky marl	0-72	73	58	231	59	75	20	36	0.6	3.4	0.9	30
3a	Mountains	Tarshiha	Chalky marl	0-60	79	70	158	37	82	17	43	0.9	4.3	0.6	24
3b		Elqosh	Chalky marl	0-50	74	25	82	35	142	19	56	1.0	4.6	1.2	15
3c		Har Biria	Chalk and marl	0-20	67	75	286	50	167	10	29	0.6	4.4	1.8	12
3d		Ein Zetim	Chalky marl	0-20	76	66	131	48	110	16	32	0.8	3.2	0.9	15
4	Brown	Kfar Masar	Basalt rock	0-51	0.5	1080	638	129	126	35	55	27	23	3.2	24
4a	Basaltic	Ulam	Basalt rock	0-50	None	1380	1190	75	93	42	35	31	30	4.1	44
4b	Soil	Lavi	Basalt rock	0-35	None	1620	1470	106	108	38	30	20	25	4.8	61
4c		Elifelet	Basalt rock	0-25	0.5	1430	1100	112	80	45	31	34	29	2.9	38
4d		Dalton	Basalt rock	0-15	0.5	1720	1400	120	95	42	36	37	21	3.7	60
10	Brown-Red Sandy Soil	Rehovot	Calcareous	0-53	29	125	320	16	32	2.4	5.3	0.8	1.7	0.4	24

Manganese. The hard limestone contains 29-57 ppm of manganese. The ratio of Mn content of the parent rock to that of terra rossa soils $\frac{\text{Mn in rock, ppm}}{\text{Mn in soil, ppm}}$ is very low (0.021-0.047). The process of weathering of the calcareous parent rock resulted in practically complete leaching of the carbonates and at the same time in the accumulation of the noncarbonate residue of the rock. The conditions of soil formation favored the accumulation of stable manganese compounds in the soil. In the semi-hard limestone and in the "Nari" the manganese concentrations were similar to those in hard limestone (50-80 ppm). Since leaching of calcium carbonate from the Mediterranean brown forest soils was more moderate than in the terra rossa's, these soils still contain relatively appreciable amounts of lime, and the manganese ratio between parent material and soils is higher – 0.065-0.15. The manganese content of the soft carbonate rocks, chalk and marl, is similar to that of the other carbonate rocks (25-75 ppm). However, the Mn content of rendzina soils is much lower than in the previously mentioned soil types. The manganese ratio between parent material and soil is 0.25-0.50.

Calcareous sandstone contains more manganese than the carbonate rocks (120 ppm); and in the resulting sandy calcareous soil the manganese ratio between parent material and soil is 0.39.

The manganese content of the parent basaltic rocks is much higher than that of the carbonate rocks (1380-1720 ppm). In the soils a lower concentration of manganese than in the parent rock was found. The parent material:soil manganese ratio is 1.10-1.69.

Zinc. The various carbonate parent rocks contain 38-80 ppm Zn. The degree of zinc accumulation in soils during their formation may be estimated from the relation between the zinc concentration in the parent material and in the terra rossa soil which (as mentioned previously) reached the stage of almost complete decalcification. In this case the ratio is 0.19-0.46, which means that the accumulation of zinc was far less than that of manganese. The zinc concentration was also low in the Mediterranean brown forest soils. The zinc ratio between chalky marl parent material and rendzinas is 0.25-0.79; the ratio in the sandy soil is 0.50.

The zinc content of basaltic rocks is higher (75-129 ppm) than that of the carbonate rocks. However, the soils formed from basalt often have a lower zinc content than their parent material. The ratio between parent material and soil zinc content is in the range of 0.81-1.40.

Copper. The copper content of carbonate bedrock is in the range of 10-22 ppm. Accumulation of this element during soil formation was relatively limited. The ratio of copper content between the hard limestone parent material and the derived soils is 0.20-0.39; for the semi-hard bedrock the ratio is 0.43-0.75; for the soft carbonate rocks and their soils, 0.34-0.56, and for calcareous sandstone, 0.45.

Basalt rocks contain higher concentrations of copper (35-45 ppm), but with one exception the soils contain less copper than their parent material.

Cobalt. The carbonate rocks are poor in cobalt (0.4-1.6 ppm), but the accumulation rate during weathering of the parent material and soil formation may reach high values. This is seen in the terra rossa soils where the ratio of cobalt content between parent material and soil is very low – 0.014-0.035. In the Mediterranean brown forest soil, the ratio is higher – 0.075-0.17; it should be remembered that these soils have retained appreciable amounts of lime. The ratio is still higher in the highly calcareous rendzinas, 0.18 to 0.25. In soils formed from calcareous sandstone the ratio is 0.47. In basaltic rock, the cobalt content (20-37 ppm) is much higher than in carbonate rocks. However, the cobalt ratio between parent material and soil is high – 0.80-1.76.

Boron. The boron content of carbonate rocks is very low (0.6-3.1 ppm), but appreciable accumulation occurs during soil formation. The highest concentration is found in terra rossa soil with a boron ratio between parent material and soil of 0.014 to 0.035. In the Mediterranean brown forest soils the ratio is 0.015-0.066, and in the rendzina soils 0.025-0.15. The accumulation of boron is higher than that of any of the other trace elements studied. Apparently the boron occurs in the parent material mainly bound to a very stable mineral such as tourmaline (3).

Appreciable boron accumulation also occurred in the sandy soils formed from calcareous sandstone. The boron ratio between parent material and soil is 0.017.

The boron content of basaltic bedrock is in the range 2.9-4.8 ppm. Boron is the only trace element in the basaltic soils which accumulated appreciably during soil formation. The boron ratio between parent material and soil is 0.060-0.093 whereas the ratios for Mn, Zn, Cu and Co are generally greater than 1.0.

From these data on the relative concentrations of trace elements in the various parent materials and the derived soils, it may be concluded that at times the soil formation processes are the determinant factor in the trace element content of the soils. Thus, no correlation exists between the trace element content of the soil and that of the parent material. In carbonate rocks, for example, the content of each of the trace elements is quite similar for all three kinds: hard limestone semi-hard limestone and chalky marl.

However, there are differences in the accumulation of various trace elements in the soils formed from these parent materials under identical conditions of climate and topography. It should be noted that the process of weathering and particularly the degree of decalcification of these three types of rock differ with respect to porosity, water permeability, percolation, and water retention (10). No relation has been found between the trace element content of the carbonate parent material and the soils formed therefrom in the case of Mn, Co, and B. On the other hand, in the case of Zn and Cu (appreciable amounts of which were lost during soil formation) the ratios of these elements in the parent rock/soil were rather similar in all three soil types (terra rossas, Mediterranean brown forest soils and rendzinas).

The weathering process of basaltic rock is accompanied by basic changes of the constituent minerals and thus also by appreciable losses in trace elements (except for boron) during soil formation; their concentration in the soil approaches that in the parent material. In this case, as in the case of Zn and Cu in soils formed from various carbonate rocks, a certain relationship is thus found between the trace element content in the parent material and the derived soils.

SUMMARY

Soil profiles originating from various parent materials (limestone, chalk, marl, calcareous sandstone, basalt, clay alluvium and dune sand) which developed under Mediterranean climatic conditions were studied with regard to content and distribution of the trace elements Mn, Zn, Cu, Co, and B. The relation between trace element content in the parent material and the derived soil was also investigated. Higher concentrations of trace elements were found in the soils formed from carbonate and basaltic bedrocks and lower ones in clay alluvial soils formed from soil alluvium originating from carbonate rocks. In sandy soils formed from calcareous sandstone or from coastal sand dunes and in peat soil the concentrations of most of the trace elements were low.

Trace element concentrations were at times higher in the A horizon of the soil profile. In soil groups of similar origin, some trace element concentrations were found to be correlated to the clay content of the soil. Concerning soils formed from carbonate rocks the concentration of most of the trace elements is determined by soil forming processes and is not correlated to the trace element content of the parent material. Basalt derived soils, however, do exhibit a certain relation between the content of most of the trace elements in the soil and that in the parent material.

Accumulation of trace elements occurred during soil formation in soils formed from carbonate rock and from calcareous sandstone; in general, the trace element content in these soils is higher than in the parent material. The order of degree of accumulation relative to the parent material is as follows: B > Mn > Co > Zn > Cu. In contrast, lower trace element concentrations, with the exception of boron, were found in soils derived from basalt and their content was often less than in the parent rock. The relative degree of accumulation in these soils judging from the composition of the parent rock, is as follows: B > Cu > Co > Zn = Mn.

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II. THE SOILS OF THE DESERT ZONE

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In contrast to soils which develop under Mediterranean climate conditions, mainly as a result of chemico-biological weathering, desert soils are principally a product of physical weathering and have very different properties. The desert soils are found mainly in the Negev, in the southern part of the country. In the formation of the Mediterranean soils leaching and dissolution of carbonate rocks, particularly the hard ones, lead to concentration in the soil of the noncarbonate residues which contain the main portion of the trace elements. In the desert soils, on the other hand, trace elements remain largely bound in the fragmented carbonate parent material, mixed with the soil in various sized fractions. In general, little information is available concerning trace elements in desert soils, although some studies dealing with trace elements in different soils have also included information on desert soil types (1, 2, 6, 7, 8). In Israel trace elements have been studied in only a few desert soils (5); it was therefore of interest to extend the available data by studying profiles of desert soils of different origins. In the present study, the distribution of the elements Mn, Zn, Cu, Co and B in the various profile horizons was determined, as well as the relationship between trace element content in the parent material and in the derived soil.

MATERIALS

SOILS

The soils were divided into three groups according to their parent material, as follows:

I *Loessial soils formed from aeolian desert dust*

1. *Loess raw soil:* A member of the loessial soils (3); loamy texture; moderate lime content; saline (Omer, Northern Negev). 2. *Loess-like raw soil:* Member of the loessial soils; sandy loam texture; moderate lime con-

tent; saline (Eshel Hanasi, Northern Negev). 3. *Loessial sandy soil:* The member of the loessial soils with the lowest clay content; poor in lime (Nir Yitzhak, Northern Negev). 4. *Desert sand dunes:* Formed by the deposition of only the sand fraction from the aeolian desert dust; poor in lime (Nitzana, Northern Negev).

II *Soils formed on bedrock or on stony alluvium*

5. *Hammada soil of mountains:* Formed on limestone; gravelly sandy loam to gravelly clay loam texture; calcareous; saline and gypsiferous (Maaleh Hameishar, Central Negev). 6. *Hammada soil of plains:* Formed mainly on calcareous debris; gravelly sandy loam to gravelly clay loam texture; calcareous; saline and gypsiferous (Hameishar, Northern Negev). 7. *Brown desert skeletal soil:* Formed on limestone; gravelly sandy loam texture; calcareous (Nevatim, Northern Negev), 8. *Desert stony land:* Patches of soil on stony land with limestone rock predominating; the soil consists of a mixture of fractions < 2 mm, gravel and stones; calcareous (Avdat, Central Negev). 9. *Reddish-yellow desert soil:* Formed from sandstone; sandy texture; moderate lime content (Dimona, Northern Negev).

III *Soils which formed from coarse desert alluvium*

10. *Coarse desert alluvium:* Alluvium of stones, gravel, coarse sand and fine soil fractions; mostly calcareous; texture of the soil (< 2 mm) is sandy and sandy loam (Beer Sheva, Northern Negev).

RESULTS AND DISCUSSION

TRACE ELEMENTS IN THE SOILS

Manganese. The highest manganese concentrations were found in the loess and the loess-like soils of Group I (512-712 ppm). A much lower manganese content was found in the loessial sandy soil (172-224 ppm) and similar values were found for the desert dune sand (Table 1). In the fine fraction of the stony-gravelly soils (soils 5-8, 10) which are formed in situ from limestone or from calcareous debris, the manganese content is often similar to that of the loessial soils (239-658 ppm). Low concentrations (275-394 ppm) of manganese are found in soil formed from sandstone (Tables 2-3).

It was reported previously (4) that a considerable similarity in both chemical composition and physical properties exists between the < 2 mm fraction of the stony-gravelly soils and the loessial soils. This similarity was

Table 1

Trace elements in soil profiles developed on desert aeolian dusty material

Soil No.	Soil	Horizon depth, cm	Concentration, ppm					
			Mn	Zn	Cu	Co	B	
							Total	H.W. soluble
1	Loess Raw Soil	0- 7	712	76	26	7.3	70	1.0
		7- 49	615	71	23	8.2	63	0.8
		49-104	625	65	22	7.1	66	0.8
		104-161	638	60	20	7.0	60	0.6
		161-212	512	55	19	6.5	63	0.4
2	Loess-like Raw Soil	0- 22	610	65	19	8.1	42	0.7
		22- 44	588	63	17	3.9	54	0.6
		44- 75	602	66	20	3.7	57	0.7
		75-113	607	64	19	5.5	60	0.8
		113-170	646	67	13	5.4	47	0.4
3	Loessial Sandy Soil	0- 11	180	31	4.9	1.6	32	0.1
		11- 42	186	26	4.8	1.2	43	0.1
		42- 83	172	24	2.7	1.4	38	0.1
		83-126	206	23	2.9	<1.0	30	0.2
		126-168	224	25	4.7	<1.0	27	0.1
4a	Desert Sand Dunes	0- 50	189	14	4.2	<1.0	33	0.2
4b		0- 50	200	15	3.7	<1.0	27	0.1

ascribed to the largely identical conditions of pedogenesis in the Negev desert (where the stony-gravelly soils are formed) and the desert of the neighboring Sinai peninsula (where the desert dusty material, which serves for loessial soils formation, originates).

Zinc. In the loessial soils group zinc content decreases from 55-76 ppm in the loess and loess-like soils to 23-31 ppm in the loessial sandy soil and to 13-15 ppm in the desert sand dunes. It should be noted that in this group of soils the clay content drops in the same sequence. The zinc concentration in soils formed on carbonate bedrock and calcareous debris (38-92 ppm) is also quite similar to that in the loessial soils. The soil containing the least amount of zinc is that formed from sandstone (22-27 ppm).

Copper. Showing a similar pattern to manganese and zinc, copper content in the loessial soil group decreases from loess and loess-like soil (13-26 ppm) to sandy loess soil and desert sand dunes (2.7-4.9 ppm). In the soils formed under desert conditions from carbonate bedrock or calcareous

Table 2

Trace elements in soil profiles developed on bedrock and stony material

Soil No.	Soil	Horizon depth, cm	Concentration, ppm					
			Mn	Zn	Cu	Co	B	
							Total	H.W. soluble
5	Hammada Soil of Mountains	0- 2	535	92	31	5.1	34	1.0
		2- 13	423	79	27	4.8	27	0.9
		13- 23	392	49	22	4.0	20	0.5
		23- 36	288	38	17	4.2	14	0.4
		Rock	150	32	14	1.0	2.1	
6	Hammada Soil of Plains	0- 15	527	91	31	7.1	38	1.4
		15- 42	540	91	28	6.2	28	1.5
		42- 50	487	87	27	6.5	27	1.5
		50- 88	482	87	18	4.3	28	1.2
		88-130	456	76	11	3.5	24	1.0
		Calcareous debris	96	35	5.1	0.9	1.0	
7a	Brown Desert Skeletal Soil	0- 38	658	46	21	5.7	31	1.0
7b		0- 34	516	68	25	10.0	34	1.6
8a	Desert Stony Land	0- 10	388	64	23	7.5	25	1.2
		Rock	165	39	11	1.9	1.5	
8b		0- 12	239	59	22	4.8	29	1.1
		Rock	98	31	13	1.2	0.8	
9	Reddish-Yellow Desert Soil	0- 46	275	27	3.2	2.9	25	1.1
		46- 79	394	22	3.5	3.2	27	1.8
		Sandstone	287	13	1.4	1.5		

Table 3

Trace elements in soil material (<2 mm) of coarse desert alluvium

Soil No.	Horizon depth, cm	Concentration, ppm					
		Mn	Zn	Cu	Co	B	
						Total	H.W. soluble
10	0-26	481	33	6.6	4.9	49	1.8
	26-33	480	27	5.0	4.4	49	2.1
	33-46	465	28	4.6	4.5	35	2.4
	46-85	380	30	3.7	6.1	30	1.7

debris the copper content is similar to that of the loess and loess-like soils (11-31 ppm). The lowest copper content is found in soil formed from sandstone (3.2-3.5 ppm).

Cobalt. In comparison to the other desert soil types, the loess and loess-like soils have a relatively high cobalt content (3.7-8.2 ppm); very low in cobalt are the loessial sandy soil and the sand dunes (<1.0-1.6 ppm). Soils formed from carbonate bedrock have a cobalt content similar to that of the loess and loess-like soils (3.5-10 ppm). The soils formed from sandstone are low in cobalt (2.5-3.2 ppm).

Boron. The concentration of boron gradually decreases from 60-70 ppm in the loess and loess-like soil to 27-43 ppm in the loessial sandy soil and desert sand dunes. The boron content of soils formed from carbonate parent material (bedrock and debris) is lower than in the loessial soils (14-38 ppm). The boron content of soils formed from sandstone is 25-27 ppm.

In most of the soils the content of water-soluble boron is greater than 1 ppm and does not exceed 2.5 ppm (Tables 1-3). In general, the trace elements manganese, zinc, copper and cobalt appear in lower concentrations in the desert soils than in the soil types formed in the Mediterranean climatic zone; boron is an exception in this respect, appearing in similar concentrations in both desert and Mediterranean soils. (Table 4)

Table 4

Trace elements in soils from the Mediterranean and Desert climatic zones of Israel

Soils	Mn	Zn	Cu	Co	B
			ppm		
Soils of the Mediterranean Zone*	34-1470	19-290	4.8-61	<1-30	12-74
Soils of the Desert Zone	172- 712	13- 92	2.7-32	<1-10	14-70

*Part I of the paper

THE DISTRIBUTION OF TRACE ELEMENTS IN THE SOIL PROFILES

In the loessial soils which consist of deep layers of desert dust sediments, variations in trace element concentration in the horizons are found only rarely; to the extent that variations do exist there is a certain decrease in trace element concentration with depth; such a gradual decrease is often observed in the hammada soils.

In the loessial soils, there is a correlation between Mn, Zn, Cu, Co and B content and the clay content of the soil. With the exception of zinc the same is true for soils formed on carbonate bedrock or calcareous debris. The correlation is especially significant (at the 1% level) in the group of loessial soils having clay originating from a common source (Table 5).

Table 5

Correlation between trace element content and clay content in profiles of soil groups of various origin

Groups of soils	Correlation coefficients				
	Mn	Zn	Cu	Co	B
Soils developed on desert aeolian dust	0.90**	0.88**	0.94**	0.89**	0.89**
Soils developed on calcareous rock and stony material	0.74**	0.41	0.59*	0.54*	0.83**

*Significant at the 5% level
**Significant at the 1% level

The relatively lower concentration of most trace elements in the desert soils in comparison with soils formed under Mediterranean climatic conditions may be ascribed largely to the higher lime content of the former.

TRACE ELEMENT CONTENT IN THE PARENT MATERIAL AND THE SOIL

The concentrations of Zn, Cu, Co and B in the limestone parent rocks of desert soils are similar to those in the limestone bedrock of the Mediterranean soils, except that the Mn concentrations are higher in the desert bedrock (Table 2). The ratios between trace element concentration in the parent material and in their respective soils are relatively high. For Mn the ratio is in the range 0.19-0.43, for Zn 0.41-0.61, for Cu 0.25-0.64, and for Co 0.18-0.25. As regards boron, the ratio is 0.028-0.10. Corresponding ratios between limestone bedrock and the derived soil were generally lower in soils of the Mediterranean zone, and in particular the much lower ratios were observed for Mn, Co and B. While under Mediterranean climate conditions trace elements concentrated together with dissolution of the carbonate, in the desert soils the lime underwent much less leaching and the trace element concentration in the soil is thus closer to that of the parent material. Likewise, in desert soils formed from sandstone the ratio between the trace element content in the parent material and that in the soils is high –0.42-0.90 for Mn, Zn, Cu, and Co.

SUMMARY

Trace element concentrations (Mn, Zn, Cu, Co and B) were studied in the profiles of desert soils originating from aeolian desert dust, limestone, calcareous debris and sandstone. The distribution of these trace elements in the profile horizons and the relation between their concentration in the parent material and in the derived soils were compared with corresponding data of soils of the Mediterranean climatic zone. The desert soils generally contained lower concentrations of trace elements, except for boron. Among the desert soils, highest concentrations of trace elements were found in the loess and loess-like soils formed from aeolian desert dust. Similar concentrations of trace elements were found mostly in residual soils formed from limestone bedrock or calcareous debris. Lower concentrations were found in the sandy soils, both in the sandy member of the loessial group as well as soils formed from sandstone.

The trace element concentration in the profile is often higher in the A horizon. A positive correlation was found between trace element and clay contents of loessial soils and of those soils formed from carbonate parent material. The high lime content of the soils accounts for their lower trace element content.

In the desert zone the trace element concentration ratio between the carbonate parent rocks and their derived soils is higher than in the case of soils formed from similar parent rocks under Mediterranean climatic conditions; this is particularly pronounced in the case of Mn, Co, and B.

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