THE FORMATION AND DEGRADATION OF BROWN-RED SOLONETZIC SANDY SOILS ALONG THE MEDITERRANEAN COAST OF ISRAEL*

by

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INTRODUCTION

The brown-red or red sandy soils of Israel are prevalent in the Sharon and Shefela along the coast of the Mediterranean Sea. They were formed in regions of sub-humid and semi-arid climates, characterized by a short and rainy winter and a prolonged and dry summer — a season of wetting and leaching alternating with a season of drying. These soils are generally thought to have originated from the calcareous sandstone called "kurkar" (13, 17, 21). It has also been suggested (24) that they have been formed from the iron-containing minerals which are concentrated in defined layers in the shifting sands; other research however (19) has resulted in the hypothesis that these soils may have developed directly from the shifting dunes with the aid of sand-loving vegetation.

The soils are mostly of the sand and sandy-loam textures. They are utilized chiefly for citrus plantations, having been found most suitable for this purpose. These soils have been described in detail elsewhere (15, 17, 21, 23).

In weathering, the parent rock, kurkar, supplies the soil with its skeleton of silicon sand grains. The colloids, which also form in the weathering process, serve as binding material. The colloidal fraction adheres to the sand grains, coating them with a fine layer and giving the soil its characteristic red or brown-red color.

The bonds between the colloids and the sand grains are unstable, break down easily, and cause the colloids to migrate downwards, bringing about the degradation of the soils. The exchangeable cations play an important part in this degradation; to a large extent, they determine the degree of stability of the bonds joining colloids to sand grains.

The work herein reported was devoted mainly to a study of the exchangeable cations in these soils, the changes in the exchangeable cation composition, and the basic effects of such changes on the composition, morphology, physical and chemical properties, and agricultural value of the soils themselves.

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Composition of Exchangeable Cations in the Soil

In the early stages of soil genesis, it is the parent material which mainly determines the composition of the exchangeable cations. As calcium is the major element released in the process of weathering, it plays the chief role in the exchange complex, and its supremacy is assured as long as kurkar remains are present (15). With the disappearance of the lime, the composition of the exchangeable cations changes, and in soils devoid of lime, exchangeable hydrogen is found. The composition of exchangeable cations varies from one soil to another, particularly with respect to the monovalent cations; there are smaller variations in the calcium and magnesium content. This study showed that sodium is prevalent in all the soils, occasionally in fairly high percentage, and accounts for 2% to 19% of the total cations. There may also be considerable potassium; in general it ranges from 1% to 17% of the total. The soils contain hydrogen in various quantities, ranging from 1% to 18%, though in another study the hydrogen content was found to be much higher (15). Exchangeable hydrogen occurs more rarely in the other soils in the country, (e.g., terra rossa) which were formed from calcareous parent material and subsequently lost their lime content. In such soils the exchangeable sodium and potassium content is also lower (18).

To facilitate the description of the brown-red soils, and for the determination of the changes in composition of the exchangeable cations during the course of their evolution, the soils were divided into two groups: (a) *solonetzic* soils, containing remains of the calcareous parent material and saturated with bases; and (b) *degrading solonetzic soils,* devoid of lime, and partly unsaturated.

Classification of the Soils According to Composition of the Exchangeable Cations

Solonetzic Soils

According to mechanical composition, these soils are sandy-loams. Lime content varies from mere traces to 2.0% and pH ranges from 7.6 to 8.1. Their exchange capacity is limited, being only 9 to 13 m.e./100 g. They contain a large amount (6—20%) of exchangeable sodium (Table 1).

Since the sodium content of the Nes Ziona soil reaches 6—12%, it may be considered solonetzic. On the other hand, the soil also contains a fairly large amount of exchangeable magnesium (33—45%) and it can also be defined as a magnesium solonetz (25), especially in view of the presence of considerable relative quantities of exchangeable sodium. High percentages of exchangeable magnesium occur occasionally in this type of soil. In the Hertzelia soil, the sodium content averages 19.0%, and it may therefore be classified as solonetz.

Degrading Solonetzic Soils

These soils are of sand, sandy-loam, and loam textures. In the course of being leached, they have lost all of their lime. The composition of 3 typical examples of such soils is given in Table 2.

Their exchange capacity ranges from 3 to 10 m.e./100 g. soil and they contain a higher than usual percentage of sodium and potassium. Unlike the calcareous solonetzic soils, these soils contain exchangeable hydrogen (1—11%). These unsaturated soils can also be considered as solonetzic soils.

TABLE 1.

EXCHANGEABLE CATIONS IN SOLONETZIC SOILS

Location	*Depth of layer (cm)*	*Total exch. cations (m.e./100 g. soil)*	*Percent of total*				*pH*	$CaCO_3$ (%)
			Ca	*Mg*	*Na*	*K*		
Hertzelia (T. 220)	0— 30	10.3	59.3	19.4	19.4	1.9	8.0	1.9
	30— 60	9.7	63.0	11.3	19.5	6.9	8.0	0.7
	60— 90	9.9	66.7	10.1	18.2	5.0	8.1	0.5
Nes Ziona (1)	0— 30	13.1	55.7	33.6	6.1	4.6	7.7	Traces
	30— 60	10.4	42.3	45.2	7.7	4.8	7.6	"
	60— 90	10.5	42.8	44.8	7.6	4.8	7.7	"
	90—120	9.1	46.1	41.8	7.7	4.4	7.7	"
	120—150	8.9	41.6	39.3	12.4	6.7	7.7	"

TABLE 2.

EXCHANGEABLE CATIONS IN DEGRADING SOLONETZIC SOILS

Location	*Depth of layer (cm)*	*Total exch. cations (m.e./100 g. soil)*	*Percent of total*					*pH*
			Ca	*Mg*	*Na*	*K*	*H*	
Raanana Vicinity (T. 233)	0— 7	3.6	58.3	11.1	8.3	16.7	5.6	7.2
	7— 35	4.8	64.6	14.6	6.2	10.4	4.2	6.9
	35— 86	4.8	70.9	10.4	6.2	10.4	2.1	7.1
Kubeiba (P. 12)	0— 36	5.4	66.7	16.7	5.6	9.2	1.8	7.0
	36— 80	10.7	58.9	19.6	2.8	8.4	10.3	6.5
	80—118	8.5	62.4	14.1	3.5	15.3	4.7	7.3
	118—133	7.1	57.8	18.3	5.6	16.9	1.4	7.6
	133—176	10.3	65.0	14.6	2.9	13.6	3.9	6.6
Ein Vered	0— 13	7.3	57.5	16.5	11.0	4.0	11.0	6.7
	13— 21	8.6	59.3	17.5	8.1	5.8	9.3	6.6
	21— 45	14.6	57.5	16.4	9.6	6.2	10.3	6.2
	45— 72	13.5	57.0	17.0	11.9	5.9	8.2	6.4

Factors in the Formation of the Solonetzic Soils

It appears that as the brown-red soils evolved in the coastal belt, certain factors aided in the penetration and establishment of sodium and potassium in the soil-complex — sometimes in excessive amounts — while other factors tended to increase the exchangeable hydrogen content. The activity of these factors was persistent, and their influence on the soil was permanent.

Of the factors which resulted in the evolution of these soils, one or more were responsible for the characteristics which define them as solonetzic soils as distinguished from the stages in the evolution of solonchak, as described by Gedroitz (4).

Two factors are capable of supplying sodium to the exchange complex of the soil: rain water, and plant residues.

Effect of Rain

Rain water may carry various quantities of salts which originate from the sea, for when rainstorms over the sea are accompanied by high winds, the sea water is swept up and blown into the falling rain.

The main soluble component of sea water is sodium chloride, and rain water has been found to contain, on the average, about 57 mg of NaCl per liter, a concentration about equal to 0.001 N solution. In analyses of rain water in this country, Menchikovsky (10) found the highest salt content in the precipitation of the coastal belt. During certain winter months, as the storms increase, the salt concentration in rain water more than doubles, and at such concentrations, considerable amounts of sodium are able to enter the exchange complex. A rise in the degree of sodium saturation presumably corresponds with closer proximities to the seashore.

During the intervals (which may be fairly long) between rainstorms, or when the rainy season ends and the soil moisture evaporates, the concentration of NaCl in the soil rises to well above what it had been in the rain water, reaching as much as 0.01 N. The field capacity of such soils ranges to more than 15%, while soil moisture may decrease to the hygroscopic point (1—3%).

Non-calcareous soils: In order to follow up the effect of NaCl on the penetration of Na, soils were treated with solutions of NaCl at various concentrations. When the soil previously saturated with Ca was leached with 0.001 N NaCl, 0.15 m.e. of Na/100 g. entered the soil, forming 3.3% of the exchange capacity (Table 3). Leaching the soil with a 0.005 N solution of NaCl resulted in appreciable adsorption of sodium — 0.4 m.e./100 g. — a quantity which raised the Na-content to 8.9% of the total exchange capacity. Passing an 0.01 N salt solution through the soil resulted in a penetration of sodium sufficient to produce solonetz. The adsorbed sodium amounted to 0.80 m.e./100 g. of soil, and it accounted for 17.8% of the total exchangeable cations.

The most concentrated solution used in the experiment, i.e., 0.01 N, could add no more than 0.01% NaCl to the soil. The soil, therefore, remains essentially unsalinized and, in the absence of excess salts, becomes solonetzic without going through the solonchak stage.

Rain water, carrying carbon dioxide, also continually introduces hydrogen to the exchange complex. The presence of carbon dioxide in rain water may, as a matter of fact, somewhat hinder the adsorption of sodium by the soil, but it cannot prevent the process entirely. The action of rain, therefore, is two-fold: it simultaneously solonetzifies and acidifies the soil. Penetration of hydrogen is possible, of course, only when the soil has lost its calcium carbonate.

Lime-containing soils: To determine the extent to which sodium can penetrate into Ca-soils in the presence of lime, finely powdered lime was added to soil samples at a rate of 5% of the weight of the soil, and they were then leached with dilute NaCl solutions. The intention was to simulate a soil still containing remnants of kurkar. It may be seen from the results (Table 3) that in the presence of appreciable amounts of powdered lime, the sodium does not penetrate the complex to the same extent as it does in the absence of lime: the maximum percentage of sodium adsorbed in the presence of lime was 4.7% of the exchange capacity, as against 17.8% in the limeless soil. The influence of lime on inhibiting sodium adsorption from dilute solutions has been previously reported (1). The formation of the solonetzic soil, or the solonetz, was accelerated, apparently, when the soils lost an appreciable part of their total lime — especially the fine lime particles.

TABLE 3.

ADSORPTION OF Na BY Ca-SOILS THROUGH LEACHING WITH NaCl SOLUTIONS

Lime added (%)	*Concentration of NaCl solution** ***N***	*Na adsorbed in m.e./10 g. Ca-soil***	*Na adsorbed (as % of exchange capacity)*
none	0.001	0.015	3.3
none	0.005	0.040	8.9
none	0.010	0.080	17.8
5.0	0.001	0.011	2.4
5.0	0.005	0.012	2.7
5.0	0.010	0.021	4.7

* Soils leached with 0.5 l. of solution.

** Exchange capacity of 10 g. of soil = 0.45 m.e./100 g.

Effect of Vegetation and Plant Residues

The vegetation may be regarded as an additional source of exchangeable sodium. Plants accumulate the sodium from soil constituents and from rain water, and during their decomposition the sodium is released and adsorbed in part by the soil-colloids. The sodium associated with organic colloids passes into the mineral colloids by ion exchange while the organic colloids receive, in turn, calcium or magnesium. In an experiment in which an Na-saturated organic complex (peat) was brought into contact with a Ca-soil of the type discussed, the Na of the organic complex exchanged almost completely with the Ca of the mineral complex (20). Contacts between the organic and mineral colloids produce reactions which result in the formation of Ca- and Mg-humates, which are more stable than the corresponding Na-humates. It follows that the exchangeable Na systematically accumulates in the mineral colloids and brings the soil to a solonetzic condition.

To check the contribution of plant residues to the exchangeable Na, ash-analyses were carried out on 4 specimens of *Eragrostis bipinnata*, which abounds on brown-red soils (29). Data are given in Table 4. Of the total relevant ash-constituents — Ca, Mg, Na, and K — Na constitutes 9—16%.

The vegetation and its residues also aid in the replacement of the Ca and Mg of the mineral colloids by the hydrogen ion, considerably accelerating the instability of the mineral colloids and affecting the degradation of the solonetzic soils. The presence of high percentages of exchangeable K in some of the soils can be attributed mainly to the effect of plants and their residues. It is known that the prevailing natural vegetation has ample supplies of potassium (17), and Table 4 shows that the ash of *Eragrostis bipinnata* contains large amounts of K, ranging from 33 to 49% of the total bases found. During the mineralization of plant residues, the potassium might have been adsorbed by the mineral colloids, either from the soil solution or through direct contact of K-humate with the Ca-Mg-mineral complex. The reaction between the K-humate and the mineral colloids could result in the accumulation of K in the latter, as was described for exchangeable Na. In part, the potassium of the complex is reabsorbed by the plants. In such soils, poor in electrolytes and devoid of lime, H replaces K (14), and this exchange further aids in the degradation of the soils.

Effects of Exchangeable Cations on Vegetation

In the brown-red sandy soils, and especially in those which are devoid of lime, the exchangeable cations constitute an appreciable proportion of the bases available to the plants. Of the total cations in the complex, Ca accounts for 42—76%; Mg, 10—45%; Na, 2—19%; and K, 1—17%. The different ratios among the cations, with the resulting ionic antagonism, might be expected to affect plant nutrition.

The ratio of exchangeable Na/K in equivalents in different soils varies between 0.2 and 10.0, and the presence of relatively large amounts of exchangeable sodium in certain soils may inhibit the uptake of potassium by vegetation. On the other hand, the varying amount of exchangeable K in the complex tends to influence the uptake by the plant of other elements, principally of magnesium (6); where there is a large amount of exchangeable K, as in some of the soils, the uptake of Mg by the plant is lowered. The ratio of exchangeable K/Mg in the soil varies between 0.1 and 1.5. These wide variations in the quantitative and relative composition of the exchangeable cations would be expected to influence the ash-composition of the vegetation, and in fact ash analysis of sand-lovegrass indicated variations in the ratios of elements — principally of magnesium (Table 4).

TABLE 4.

ASH COMPOSITION OF *ERAGROSTIS BIPINNATA*

Sample No.	*Location*	*Soil texture*	*Ash (% dry matter)*	SiO_2		Al_2O_3-Fe_2O_3		CaO		MgO		Na_2O		K_2O	
				% dry matter	*% of ash*	*% dry matter*	*% of ash*	*% dry matter*	*% of ash*	*% dry matter*	*% of ash*	*% dry matter*	*% of ash*	*% dry matter*	*% of ash*
1	Beit Lid	loam	6.67	5.28	79.2	0.11	1.7	0.23	3.4	0.17	2.5	0.16	2.4	0.43	6.4
2	Eliashev	sand	4.41	2.30	52.1	0.07	1.6	0.33	7.5	0.55	12.5	0.13	3.0	0.40	9.1
3	Rishon le Zion	sand	4.53	2.94	64.9	0.14	3.1	0.33	7.1	0.30	6.6	0.11	2.3	0.41	9.0
4	Tel Zur	sand	4.54	2.88	63.4	0.13	2.9	0.32	8.8	0.20	4.5	0.12	2.7	0.42	9.2

Similarly, in citrus groves, differences in the quantitative and relative composition of the exchangeable cations are likely to be reflected in the uptake of bases by the citrus trees, in the development of the trees, the chemical composition of their parts, and in their productive yields and fruit quality. The citrus plantations of this country are concentrated mainly on these brown-red sandy soils. A deficiency or excess of any element in the soil, if not balanced by proper fertilizing, harms the nutrition of the plant. Magnesium-deficiency, found in certain citrus orchards by Heymann-Herschberg (5) is apparently related to the small amounts of exchangeable Mg in some of the sandy soils, or to the high K/Mg ratio in the complex.

Degradation of the Soils

The process of degradation of the soils is influenced largely by the nature of the exchangeable cations of the colloids that coat the silicon sand grains. The partial unsaturation of the soil, on the one hand, and the presence of relatively large amounts of Na, on the other, tend to lessen the stability of the colloids. As for the exchangeable K, its influence on soil properties is not so deleterious as that of Na (28). The characteristic properties of the colloids of solonetzic soils or solonetz are: marked Na hydrolysis, strong hydration, large dispersion capacity, and alkaline reaction. A few of these properties are inhibited and weakened by the presence of H in company with the Na. The degradation occurs when the colloid coating separates from the silicon grain and migrates downwards. When enough has accumulated it forms compact but plastic layers, disrupting the movement of both water and air. This phenomenon is typical of "Nazaz" soils (9, 11, 15, 21), which may be viewed as an extreme stage of degradation.

Table 5 presents the composition of exchangeable cations, pH, and the mechanical analysis of degraded soils, one of which (R.480) has reached the stage of typical Nazaz. These soils contain no lime. The clay, owing to its migration from the upper horizons, has accumulated in the deeper layers. In the degradation process, the amounts of exchangeable Na and K apparently decreased, while the H-content rose. Conditions of unsaturation bring about: partial decomposition of the colloids to oxides of Si, Al, and Fe; formation of an upper gray, leached horizon; and illuvial layers in depth (15, 17), as in the process of solodization. Gedroitz (3) points out that solonetz or solonetzic soils undergoing degradation constitute a specific soil, similar in some ways to soils in various stages of podzolization; he termed them "solod", and the process of their formation "solodization". Solonetz soils, in their stage of transition to solod, are defined by Kellogg (8) and Rost (25) as solodized solonetz.

The brown-red sandy soils cannot become true solod since, even during degradation, they cannot lose their exchangeable Na which continues to enter from its permanent source — the sodium chloride of rain water.

TABLE 5.

EXCHANGEABLE CATIONS AND MECHANICAL COMPOSITION OF DEGRADED SOILS

Location	Depth of layer (cm)	Total exch. cations (m.e./100 g. soil)	Percent of total					pH	Mechanical comp.(%)			
			Ca	Mg	Na	K	H		clay	silt	fine sand	coarse sand
Rehovot (R. 480)	0— 39	10.1	59.4	15.8	3.0	4.0	17.8	—	10.6	2.1	75.3	12.0
	39— 69	11.1	65.8	13.5	2.7	2.7	15.3	—	12.2	1.6	74.6	11.6
	69—104	18.8	68.6	17.0	2.7	2.1	9.6	—	28.8	1.5	61.9	7.8
	104—125	19.1	70.7	21.5	2.6	2.1	3.1	—	23.2	2.9	63.4	10.5
Ra'anana vicinity (T. 539)	0— 30	4.6	76.2	13.0	4.3	2.2	4.3	6.9				
	30— 60	4.6	65.2	19.6	4.3	2.2	8.7	6.8				
	60— 90	6.8	72.1	17.6	2.9	1.5	5.9	6.6				
	90—120	9.0	72.2	15.6	4.4	1.1	6.7	6.2				

Morphology of the Soils

The solonetzic and solonetz soils which we examined do not have the specific morphology often attributed to soils of this type. Their morphology does not differ from that of regular soils of similar texture which are free of excess exchangeable Na. On the other hand, Storie (27) has found that soils described morphologically as solonetz contained exchangeable Na in the same amounts as normal Californian soils. Kelley (7), in examining several profiles described by other workers (2, 26) as solonetz according to their morphology, found that in most cases these soils contained over 85% of Ca + Mg.

The two definitive properties of solonetz soil — specific exchangeable cation composition and specific morphology — are not always exhibited simultaneously.

As for the brown-red degrading solonetzic soils, we consider their morphology to be typical for soils affected by similar processes.

The soils discussed show a friable A-horizon and a compact B-horizon of columnar and cloddy structure known as the "Nazaz" horizon. The transition from A to B is sharp. The soils contain only the usual amounts of exchangeable Na. The excess of exchangeable Na, which may have been present at one time was apparently lost during degradation. We may assume, therefore, that the Na played its part in the degradation of the soil, but eventually disappeared as this process progressed.

SUMMARY

Some of the brown-red sandy soils along the Mediterranean coast of Israel are of a solonetzic nature. They may be subdivided into : (a) solonetzic soils, (b) degrading solonetzic soils.

It is assumed that during the various processes resulting in their formation

the Na, characteristic of solonetzic soils, was supplied to the exchange complex by NaCl-containing rain, and by vegetation.

These solonetzic soils do not show the specific morphology generally attributed to soils of this type.

They are, in part, undergoing degradation. The presence of large amounts of exchangeable Na and H relative to the exchangeable Ca + Mg content causes instability of the clay and its migration downwards. Degradation brings about basic changes in the morphology of the soils: a thin, loose, sandy layer is formed in the A-horizon, while the B-horizon is heavy and impervious, with a columnar structure ("Nazaz").

The process of degradation in the brown-red sandy soils is similar to the process of solodization.

The total quantity and composition of the exchangeable cations in the different soils often vary widely, thus significantly affecting the balance of elements available to the plant.

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