

Modern Aspects of Sampling and Sodium Balance Studies in Salt Affected Areas

K. DARAB

*National Institute for Agricultural Quality Testing,
Budapest (Hungary)*

The salt affected soils, their degree of salinization and alkalinization can be characterized by the amount and chemical composition of water soluble salts and/or by the degree of sodium saturation in them and in their different horizons. The methods of analyses used and the limit values of salinity and alkalinity are by no means uniform. They vary in the different regions, countries, or even in the various laboratories of the same country. Differences in methods and limit values may be accepted

- under different climates,
- when salt affected soils of various origins are examined.

The methods selected for the study of salt affected soils as well as the limit values of salinity and alkalinity always depend on the purpose of the investigations.

Laboratory facilities may also play a decisive role when the most suitable methods for analytical work related to soil salinity and/or alkalinity are selected. All the standardized systems for soil analyses are based on theoretical considerations as well as on practical experiences, and any deviation from these methods may cause differences in the analytical results.

Using the same methods, it is necessary to know the systematic and random errors of the analyses for a proper evaluation of the determined soil properties.

In order to compare and to evaluate data determined by various methods, we have to know the causes and the magnitudes of the deviations brought about by the differences in the analytical methods.

The accuracy of the determination of soil salinity and alkalinity is influenced not only by the error of the analyses but by several other factors as well, which are independent of the methods of analyses.

These factors include:

- a) the uneven vertical and horizontal distribution of water soluble salts and exchangeable cations in soils;
 - b) the processes of accumulation and leaching of water soluble salts;
 - c) the periodical changes of accumulation and leaching processes.
- a) Already at the beginning of this century the heterogeneity of soil properties was recognized by several authors. In the early years of his activity — while investigating the salt affected areas of the Hungarian Plain — 'SIGMOND observed and described that the total amount of water soluble salts was widely variable both in their horizontal and vertical sections in soils

[5–7]. His studies and achievements have contributed very much to further investigations in this field of soil science and his basic conclusions on the correlation between the salinity of soil horizons and the mineralization of waters, underground layers, etc. are still valid [8, 9].

Due to the uneven distribution of water soluble compounds, a single sample, in most of the cases, does not represent a soil profile, a spot, and still less an area. Different methods and systems of sampling have been employed in the successive stages of the development of soil science in order to overcome these difficulties [1–4, 9]. Profiles of salt affected soils were sampled at regular intervals according to the genetic horizons as early as the beginning of this century. By this method of sampling we can characterize the vertical distribution of compounds in the profile. Later, sampling methods were developed which made possible statistical evaluations and the calculation of the variations in soil properties, both vertically and horizontally.

Sampling systems for salt affected soils may be somewhat different from those used for other soils. These differences can be related to certain peculiarities of alkali and saline soils. The horizontal and vertical variations in the quantities of the mobile sodium compounds are influenced by different factors, such as:

- the depth of the water table and the mineralization of the groundwater;
- natural and artificial drainage;
- the meso and micro relief of the place of sampling.

Due to these factors and their relative importance, in most of the cases the salt affected soils form meso- and micro-complex populations of soils with various degrees of salinization and/or alkalization. A simple random sampling, therefore, is not always acceptable for the survey of areas covered with salt affected soils.

The selection of the sampling method depends on the purpose of the investigation. Different methods and systems of sampling have to be applied for soil survey, soil amelioration, irrigation or for the control of the effects of soil amelioration and irrigation on soil properties.

b) and c). The regime of soluble salts and mobile compounds in soils may involve several errors in sampling. Without knowing the salt regime and its periodical changes, the evaluation of the salinity and alkalinity status of soil profiles, spots and areas might be erroneous and misleading even if we use the most proper method of sampling. Unfortunately, in technical literature there are not many data which conclude to the determination of error due to soil heterogeneity and to the regime of mobile compounds in salt affected soils.

Methods and materials

For the determination of the effect of factors influencing the error of samples, investigations were carried out in an area covered by soda-saline soils. The native vegetation indicated a micro-complex distribution of soils with different degrees of salinity and alkalinity. The mineralized groundwater near the surface seemed to be the main factor in the formation of the salt affected soils.

The total sampled area was 100 hectares. Sampling was carried out in random distribution on the whole area and in spots having different sizes, as follows:

1. a) 3.14 m² with 6 profiles
 b) 3.14 m² with 6 profiles
2. a) 0.5 hectare with 6 profiles
 b) 0.5 hectare with 6 profiles
3. a) 1 hectare with 6 profiles
 b) 1 hectare with 6 profiles
 (a & b indicate parallel samplings)

4. 1 hectare with 12 profiles

5. 100 hectares with 6 profiles.

In case of 1/a and 1/b the profiles were taken from round spots (radius: 1 m).

The profiles were sampled from the genetic horizons at regular intervals, down to the water table.

The six profiles of the 100-hectare-area were sampled always in the same months, for four years.

The degree of salinity and alkalinity was determined from each sample by the following methods:

The amount and chemical composition of water soluble salts from the saturation extract as well as from the 1 : 5 aqueous extract;

The quantities of mobile and exchangeable sodium by the ammonium acetate and the isotope dilution methods;

The CEC-values after sodium-saturation by the ammonium acetate method.

The above-mentioned determinations were also carried out in six parallel runs from the composite samples of twelve profiles collected on one hectare in order to determine the error of analyses.

On the basis of the analytical results of the parallel determinations, the means, the standard deviations and the coefficients of variations were calculated.

To compare the different methods (e.g. methods 1 and 2 below) the observed means were compared and the standard deviation of the difference of the means was calculated.

$$\bar{S}_d = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})_1^2 + \sum_{i=1}^n (x_i - \bar{x})_2^2}{n(n-1)}} \quad (1)$$

\bar{S}_d = standard deviation of the difference of the means.

$(x_i - \bar{x})_1$ = the difference between the value measured in the *i*-th parallel and the mean of *n* determined by method 1.

$(x_i - \bar{x})_2$ = the same by method 2.

n = number of parallel determinations

or

$$\bar{S}_d = \sqrt{\frac{S_1^2 + S_2^2}{n}} \quad (2)$$

S_1 = standard deviation of the values determined by method 1.

S_2 = standard deviation of the values determined by method 2.

Equation 1 was applied if the standard deviations of data determined by methods 1 and 2 were similar. In the cases of different variations we applied equation 2.

To check the similarity of standard deviations, we used the F -test.

$$F = \frac{S_a^2}{S_b^2} \quad (3)$$

S_a = the higher value of standard deviations,

S_b = the lower value of standard deviations.

The confidence limits were calculated with the Student „ t ”-test.

To evaluate the salinity and alkalinity of spots or areas, it is necessary to know the distribution of sodium compounds in the different layers within the soil profile and to calculate the reserves of mobile sodium compounds in the investigated soil layers.

For the determination of the mobile sodium reserves of the sampled spots, the weighted means of the mobile, exchangeable and soluble sodium contents of the sampled profiles were calculated:

$$\overline{Na} = \frac{\sum_{i=1}^n Na_i \cdot a_i}{\sum_{i=1}^n a_i} \cdot 100 \quad (4)$$

\overline{Na} = the weighted mean of the quantity of sodium compounds in the soil profile, me/100 g

Na_i = the mobile sodium content in the sample from the i -th layer, me/100 g

a_i = the weight of the i -th layer in g.

The weighted mean of the quantity of sodium may be considered as the sodium reserve of the soil profile between the 1st and n -th layers.

The means of the mobile sodium reserves of the sampled spots were calculated from the weighted means of the mobile sodium contents in the sampled profiles.

For comparing the mobile sodium reserves of spots of different sizes, the means were compared and the standard deviation of the mean of differences was calculated.

In the cases of an equal number of profiles equations 1 and 2 were used. If the numbers of profiles on the compared spots were unequal, we applied the following equations:

$$\bar{S}_d = \sqrt{\frac{\left(\sum_{i=1}^n (x_i - \bar{x})_1^2 + \sum_{i=1}^n (x_i - \bar{x})_2^2 \right) (n_1 + n_2)}{n_1 \cdot n_2 (n_1 + n_2 - 2)}} \quad (5)$$

$$\bar{S}_d = \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}} \quad (6)$$

\bar{S}_d = standard deviation of the difference of means in the mobile sodium content measured on spot 1 and spot 2.

$(x_i - \bar{x})_1$ = the difference between the sodium reserve determined in the i -th profile and the mean of sodium reserves in n_1 profiles on spot 1.

$(x_i - \bar{x})_2$ = the difference between the sodium reserve determined in the i -th profile and the mean of sodium reserves in n_2 profiles on spot 2.

n_1 = number of profiles on spot 1.

n_2 = number of profiles on spot 2.

S_1 = standard deviation of the sodium reserves of profiles on spot 1.

S_2 = standard deviation of the sodium reserves of profiles on spot 2.

The „ F' ”-test was used to check the similarity of standard deviations. The confidence limits were calculated by the Student „ t' ”-test.

Results and discussion

For the characterization of the salinity and alkalinity status of soil profiles, it is necessary to determine the quantities of mobile, water soluble and exchangeable sodium compounds.

The mobile sodium content can be measured either by the ammonium acetate- or by the isotope dilution method. The amount of sodium in the ammonium acetate extract gives the total of soluble and exchangeable sodium. The same forms of sodium can be determined by the isotope dilution method. With both methods the error of analyses is within the limits of acceptability. In the case of six parallel analyses the coefficient of variation is less than three percent for the ammonium acetate method and about six percent for the isotope dilution method (Table 1). The isotope dilution method gives higher values in every case than the ammonium acetate method. The difference between the amounts of mobile sodium determined by the two methods is more than the error of analyses, and the differences of the means are characteristic on 99% confidence level.

In the case of analysing a spot with random distribution of twelve profiles, the mobile sodium contents determined by the ammonium acetate- and the isotope dilution methods differ. The differences are less than the error of samples and the means of the differences are not characteristic on 95% confidence level (Table 1).

Exchangeable sodium is calculated from the quantities of mobile sodium compounds by subtracting the amount of water soluble sodium. The comparison of the values determined by the ammonium acetate- and the isotope dilution methods gives the same results as in the case of the determination of mobile sodium. The accuracy of the determination by either of the two methods is acceptable. The coefficients of the variations are about six percent with the ammonium acetate- and about ten percent with the isotope dilution method. The differences between the amounts of exchangeable sodium determined by the two methods are more than the error of analyses but less than the error of samples and in this case the difference of means is not characteristic on 95% confidence level.

The isotope dilution method has the advantage that in the soil–water equilibrium system the characteristic values (pH, the solubility of salts and the colloid-chemical state of the adsorbent) are more similar to the original properties of soil samples than in the case of the ammonium acetate method. The error of analyses of the isotope method is somewhat higher than that of the ammonium acetate method but it is much less than the error of sampling.

Table 1.

The error of analyses (A) and the error of samples (B) in the determination

Depth, cm	Number of parallel analyses	Freedom grade	Mobile Na						$\bar{N}_{a_2} - \bar{N}_{a_1}$	S_d
			NH ₄ acetate method			Isotope dilution method				
			\bar{N}_{a_1}	S_1	CV ₁	\bar{N}_{a_2}	S_2	CV ₂		
			me/100 g			me/100 g				
A.										
0-3	6	10	10.6	0.29	2.7	11.98	0.48	4.0	1.38	0.23
3-10	6	5	11.05	0.26	2.4	13.58	1.25	9.0	2.53	0.52
10-20	6	5	13.92	0.31	2.2	15.85	0.70	4.4	1.87	0.31
20-30	6	5	9.28	0.34	3.0	12.38	0.95	7.7	3.10	0.41
30-50	6	5	6.25	0.17	2.7	7.03	0.43	6.1	0.78	0.19
B.										
0-3	12	22	13.91	3.61	25.9	12.62	2.75	21.8	-1.29	1.31
3-10	12	22	14.20	3.00	21.1	16.61	3.96	33.0	2.41	1.41
10-20	12	22	16.52	2.80	16.9	18.04	3.38	18.7	1.52	1.26
20-30	12	22	11.05	2.26	20.4	12.12	2.41	19.9	1.07	0.94
30-50	12	11	7.33	1.59	21.6	7.48	3.71	50.2	0.15	1.18

For the subsequent evaluations we decided to use the quantities of mobile and exchangeable sodium determined by the isotope dilution method.

The water soluble sodium compounds can be determined either from the saturation extract or from the 1 : 5 aqueous extract.

The analyses of saturation extracts and 1 : 5 aqueous extracts give the same general picture of the distribution of soluble sodium within the soil profile (Fig. 1). The numerical values of sodium contents determined in the saturation extracts and in the 1 : 5 aqueous extracts differ from each other.

If we analyse samples of twelve profiles collected from one hectare, there are more differences between the sodium quantities measured in saturation extracts and 1 : 5 aqueous extracts than the error of samples, and the differences of means are characteristic on 95% confidence level (Table 2). The amounts of sodium ions determined in saturation extracts were selected for the further evaluation of the distribution of soluble sodium. The results of analyses, carried out in six replications from the same samples, indicate that the error of analyses is less than 10% for soluble sodium (Table 3).

The analyses of a representative soil profile show that the soils of the investigated area contain a high amount of water soluble salts. The maximum quantities of water soluble salts occur on the surface of the soils, and decrease slowly in the deeper horizons, nearer to the water table. The depth of the water table varied between 0.7-1.5 m in the period of survey. Sodium carbonate and bicarbonate amount to more than sixty percent of the total salt content and their ratio decreases — with the decrease of the total salt content — to 50-40% in the deeper layers. Due to the high amount of sodium carbonate, the pH values of the saturation extracts are between 9-10. The concentration of calcium and magnesium is very low and in the solutions the sodium ions dominate. As a result of the excess of sodium ions, the soil is saturated with sodium up to 80-90 percent (Table 4).

of mobile and exchangeable sodium on a spot 1 ha in extent

t	Exchangeable Na						Freedom grade	\bar{S}_d me/100 g	t
	NH ₄ acetate method			Isotope dilution method					
	N ₃	S ₂	CV ₃	N ₄	S ₄	CV ₄			
	me/100 g			me/100 g					
6.0	7.15	0.58	8.1	8.53	0.76	8.9	10	0.37	3.73
4.87	7.82	0.39	5.0	10.35	1.38	13.3	5	0.58	4.26
6.20	10.02	0.76	7.6	11.95	1.15	9.6	5	0.56	3.45
7.56	7.51	0.36	4.4	10.61	0.97	9.2	5	0.41	7.55
4.11	4.73	0.27	5.7	5.51	0.53	9.6	10	0.24	3.25
0.99	7.37	3.10	42.0	6.30	2.33	37.0	22	1.12	1.15
1.67	9.64	2.49	25.8	12.04	3.66	30.2	22	1.27	1.90
1.06	12.56	2.26	18.0	14.07	2.57	18.3	22	0.99	1.53
1.12	8.75	1.44	16.4	9.80	2.32	23.7	22	0.79	1.33
0.13	6.45	1.59	21.6	6.60	3.79	57.4	11	1.17	0.13

The other type of soda-saline soils in the sampled area is the sodium-carbonate-solonchak-solonetz. Characteristically of this type of saline soil, the maximum of sodium salts occurs in the B₁-horizon (Table 4). The concentration

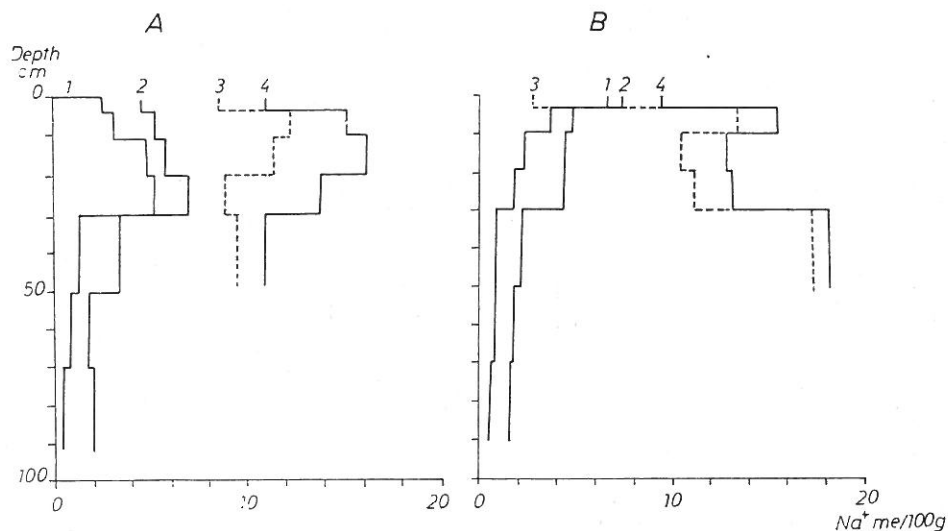


Fig. 1

The distribution of mobile sodium compounds in two typical soil profiles of the investigated area. A. Soda solonchak-solonetz. B. Soda solonchak. 1. Water soluble sodium in the saturation extract; 2. Water soluble sodium in the 1 : 5 aqueous extract; 3. Exchangeable sodium; 4. Mobile sodium

Table 2

The quantities of sodium compounds determined

Depth, cm	Number of samples	Freedom grade	\bar{Na}_1^+	\bar{Na}_1^+	$\bar{Na}_1^+ - \bar{Na}_1^+$
			in saturation extract	in 1:5 aqueous extract	
			me/100 g		
0-3	12	22	6.33	7.02	0.69
3-10	12	22	4.54	6.35	1.81
10-20	12	22	3.97	5.88	1.91
20-30	12	22	2.32	4.25	1.93
30-50	12	11	0.88	2.74	1.86
50-70	7	12	0.71	2.06	1.35
70-90	6	10	0.67	1.77	1.10

of salts in the saturation extracts is somewhat less than in the case of sodium-carbonate-solonchak. Among the water soluble salts sodium carbonate and bicarbonate prevail, both having a maximum concentration in the B_1 -horizon. Due to the prevalence of sodium carbonate and bicarbonate, the soil is saturated with sodium up to 60-80 percent. The amount of mobile and exchangeable sodium shows maximum values in the B_1 -horizon in both of the soil profiles. We collected samples of 6 profiles from spots 1/a and 1/b. Spot 1/a represents mainly sodium-carbonate-solonchak, and spot 1/b represents sodium-carbonate-solonchak-solonetz. The general picture of the distribution of mobile,

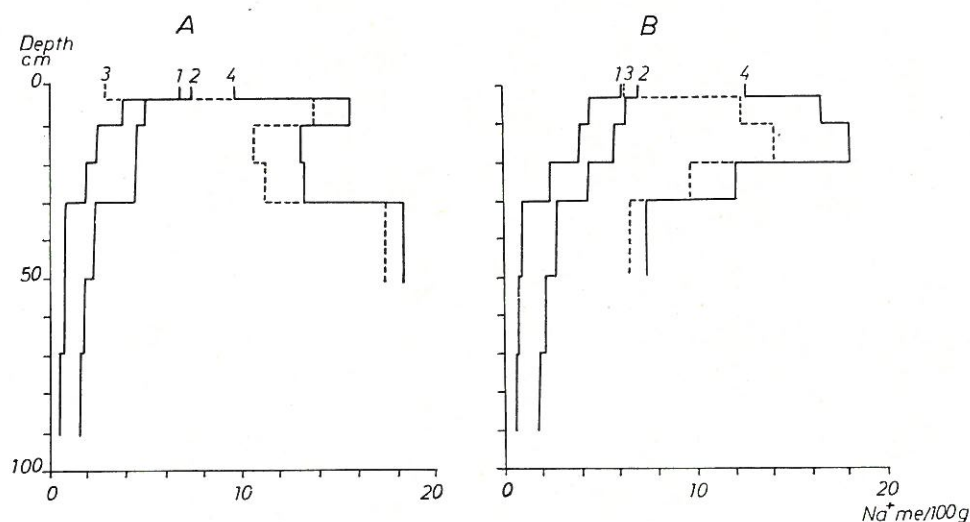


Fig. 2

The distribution of mobile sodium compounds in a solonchak soil profile and in the averages of twelve profiles. A. Soda solonchak profile. B. The average of twelve profiles. 1.-4. See: Figure 1

in saturation extracts and 1:5 aqueous extracts

$S_{Na_1}^2$	$S_{Na_2}^2$	S_d	F	t	Confidence limit me/100 g
10.810	4.780	1.150	2.28	0.57	2.38
1.650	2.600	0.520	1.56	3.48	1.07
2.000	3.210	0.660	1.60	2.91	1.36
1.530	1.550	0.506	1.01	3.81	1.05
0.080	0.410	0.202	5.12	9.24	0.44
0.014	0.051	0.096	3.67	14.10	0.21
0.077	0.083	0.163	1.07	6.75	0.36

exchangeable and water soluble sodium within the soil profile is the same in the typical soil profiles as that given by the means of profiles on small spots covered dominantly by one of the two soil types (Table 5). These two soils differ from each other not only in the vertical distribution of mobile sodium compounds but in the quantities of mobile sodium reserves, as well. The differences of the means of mobile and exchangeable sodium reserves of the

Table 3

The error of analyses in the determination of water soluble sodium from saturation extracts

Depth, cm	Number of parallel analyses	SP	S_{Sp}	pH	S_{pH}	Na ⁺	S_{Na}	CV _{Na}
						me/l		
0-3	6	33.1	0.8	9.95	0.10	104.2	7.40	7.1
3-10	6	39.2	0.3	9.95	0.10	84.6	3.12	4.1
10-20	6	57.7	1.3	9.59	0.15	67.8	7.51	11.1
20-30	6	54.1	1.8	9.46	0.02	32.6	0.40	1.23
30-50	6	35.6	0.9	7.96	0.27	42.3	2.60	6.14

two spots are characteristic on 95% confidence level. The variation of the mobile sodium contents is less on spot 1/b than on spot 1/a. In the case of spot 1/b every sampled profile belongs to the sodium-carbonate-solonchak-solonetz type and on spot 1/a five out of the six profiles represent sodium-carbonate-solonchak and one of them belongs to the sodium-carbonate-solonchak-solonetz type (Table 6). The same distribution of soils could be observed in the case of sampling the 1/a spot and one hectare. From the twelve sampled profiles ten represent sodium-carbonate-solonchak and two sodium-carbonate-solonchak-solonetz. The mean of mobile sodium reserve is the same as in spot 1/a, and the difference is not characteristic on 95% confidence level (Table 7 and Fig. 2).

Table 4
The chemical composition of saturation extracts and the amount of exchangeable sodium in a solonchak profile (A)
and in a solonchak-solonetz soil (B) of the investigated area

Depth, cm	SP	EC	pH	meq/l							Cl ⁻	Exch. Na	CFC
				Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	SO ₄ ²⁻			
A.													
0-3	33.4	10.11	9.8	1.41	1.15	176.0	1.43	31.8	76.4	29.20	39.6	3.23	—
3-10	33.9	8.39	9.7	2.40	4.16	113.6	0.67	14.3	55.3	8.94	31.1	4.99	6.96
10-20	36.0	5.08	9.1	1.74	3.02	66.5	0.82	4.0	38.4	1.60	28.8	9.79	10.95
20-30	40.0	3.72	9.2	0.96	1.39	49.6	0.25	1.5	22.4	3.60	27.3	6.50	8.70
30-50	37.2	1.49	8.5	2.24	1.83	22.7	0.79	—	13.1	6.25	12.5	5.35	—
50-70	31.6	2.26	8.3	2.09	2.60	23.2	0.44	—	19.3	7.10	12.4	—	—
70-90	33.2	1.97	8.9	1.24	1.91	20.5	0.46	—	18.6	—	—	—	—
B.													
0-3	48.2	2.89	8.7	3.64	3.22	51.1	0.75	—	40.2	6.80	7.6	12.76	9.60
3-10	45.5	5.12	9.5	1.22	2.11	65.7	0.35	15.0	30.8	—	13.3	10.06	13.56
10-20	65.2	3.49	9.7	0.81	0.82	74.0	0.38	8.2	42.4	2.30	19.5	11.29	16.50
20-30	66.8	5.86	9.6	0.53	2.17	75.0	0.22	9.0	39.7	2.50	28.1	9.55	17.15
30-50	50.4	2.10	9.0	1.38	1.15	25.2	0.41	8.0	15.6	4.50	9.1	10.91	13.40
50-70	30.0	2.20	8.6	2.58	3.78	23.2	0.53	7.0	10.5	4.70	10.0	—	—
70-90	28.2	2.58	8.7	1.80	1.72	14.9	0.34	3.4	8.0	2.14	6.2	—	—

Table 5

The distribution of mobile sodium in two typical spots of the sampled area

Sampled spot, m ²	Number of profiles	Depth, cm	Mobile Na			Exchangeable Na			Soluble Na		
			\bar{N}_{a_1}	S_1	CV ₁	\bar{N}_{a_2}	S_2	CV ₂	\bar{N}_{a_3}	S_3	CV ₃
			me/100 g			me/100 g			me/100 g		
1/a 3.14	6	0-3	12.27	1.76	14.3	8.72	0.83	9.5	3.55	1.56	44.2
		3-10	14.48	1.59	11.0	11.93	1.86	15.5	2.55	0.41	16.1
		10-20	14.10	1.24	9.1	11.50	1.30	11.1	2.60	0.80	30.4
		20-30	13.67	1.84	13.4	11.85	1.39	11.7	1.82	0.34	18.6
		30-50	6.86	1.59	23.2	5.57	1.42	25.5	1.31	0.23	17.9
		weighted mean		11.20	1.16	10.3	9.22	0.86	9.3	1.98	0.63
1/b 3.14	6	0-3	9.87	0.94	9.5	7.62	0.89	11.7	2.25	0.17	7.5
		3-10	11.03	0.96	8.7	8.42	0.97	11.5	2.61	0.41	15.5
		10-20	11.67	0.96	8.3	7.61	1.25	16.5	4.06	2.46	58.0
		20-30	10.07	0.68	6.7	7.51	0.38	5.2	2.56	0.65	25.5
		30-50	7.05	1.09	15.4	5.58	0.65	11.8	1.47	0.76	51.4
		weighted mean		9.25	0.79	8.5	6.85	0.5	7.3	2.4	0.45

$\bar{S}_d = 0.574$ $t = 3.39$ $\bar{S}_d = 0.406$ $t = 3.38$ $\bar{S}_d = 0.316$ $t = 0.$

Table 6

The weighted means of mobile and exchangeable sodium in profiles on spots 1/a and 1/b

Spot	No of profile	Mobile Na	Exchangeable Na
		me/100 g	
1/a	I	9.17	7.43
	II	11.16	9.30
	III	11.62	19.60
	IV	12.72	10.30
	V	11.50	9.10
	VI	11.03	9.68
Mean		11.20	9.22
	S =	±1.16	±0.74
	\bar{S} =	±0.475	±0.35
99% confidence interval		13.11 - 9.30	10.63 - 7.81
1/b	I	9.20	7.10
	II	8.10	6.15
	III	9.44	7.30
	IV	10.22	7.35
	V	9.92	6.87
	VI	8.65	6.33
Mean		9.25	6.85
	S =	±0.79	±0.50
	\bar{S} =	±0.32	±0.20
99% confidence interval		10.55 - 7.95	7.67 - 6.03

The reserves of mobile, exchangeable and soluble sodium in the 0–50 cm layer were calculated for spots of different sizes and from different numbers of sampled profiles. The means calculated for spots of different sizes and for different numbers of profiles are very close to each other. If we compare the data of samples collected from two 0.5 ha spots, or from two 1 ha spots, or even

Table 7

The weighted means of mobile sodium in twelve profiles collected from one hectare

No. of profile	Mobile Na in the 0–50 cm layer me/100 g
111	13.75
112	12.20
113	11.20
114	11.90
115	12.35
116	10.45
117	12.42
118	15.25
120	10.70
121	11.80
122	13.15
123	13.05
mean	12.35
S =	±1.37
CV =	11.1%

Profiles No. 116 and No. 120 are soda-solonchak-solonetz.

if the data of samples collected from one hectare are compared to those of samples coming from 100 hectares with random distribution of 12 and 6 profiles, the differences of the means of mobile, exchangeable and water soluble sodium reserves are within 95% confidence intervals. The similar values of mobile sodium reserves show that the sodium compounds are distributed uniformly on the total sampled area. The coefficient of variation increases only very slowly with the increase of the size of the sampled spot (Table 8 and 9).

The data are in accordance with observations revealing that soils with different degrees of salinization and alkalinization form microcomplex population on the sampled area. In this microcomplex population the extent of sodium-carbonate-solonchak soils represents about 80–85 percent, and the rest of the area is covered by sodium-carbonate-solonchak-solonetz.

The amount of soluble sodium in the 0–50 cm soil layer did not change in the four years of observation and the weighted means of sodium salts varied between 3.0 and 3.8 me/100 g. The difference of the means is within the 95% confidence interval.

At the same place we measured an increase in the exchangeable sodium reserves from 6.22 me/100 g to 10.8 me/100 g. The increase of the exchangeable sodium is characteristic on 95% confidence level. This indicates the progressive alkalinization of soils in the investigated area.

Table 8
 The means of mobile sodium reserves in the 0—50 cm layer of
 the sampled spots and area

The size of spot	Number of profiles	Mobile Na	Exchangeable Na	Soluble Na
		me/100 g		
1/a 3.14 m ²	6	11.2 me/100 g s = ±1.16 CV = 10.3%	9.22 me/100 g s = ±0.86 CV = 9.3%	1.98 me/100 g s = ±0.63 CV = 31.8%
1/b 3.14 m ²	6	9.25 me/100 g s = ±0.79 CV = 8.5%	6.85 me/100 g s = ±0.5 CV = 7.3%	2.40 me/100 g s = ±0.45 CV = 18.8%
2/a 0.5 ha	6	11.34 me/100 g s = ±1.19 CV = 10.4%	8.83 me/100 g s = ±0.91 CV = 10.3%	2.51 me/100 g s = ±0.77 CV = 30.6%
2/b 0.5 ha	6	10.06 me/100 g s = ±1.65 CV = 15%	8.18 me/100 g s = ±1.55 CV = 19%	1.82 me/100 g s = ±0.38 CV = 20.8%
3/a 1 ha	6	11.02 me/100 g s = ±2.11 CV = 19.1%	8.88 me/100 g s = ±1.43 CV = 16.1%	2.14 me/100 g s = ±0.62 CV = 28.8%
3/b 1 ha	6	11.32 me/100 g s = ±1.13 CV = 10%	8.13 me/100 g s = ±1.17 CV = 14.3%	2.19 me/100 g s = ±0.79 CV = 36%
4 1 ha	12	12.35 me/100 g s = ±1.37 CV = 11.1%	10.18 me/100 g s = ±1.48 CV = 14.5%	2.17 me/100 g s = ±0.68 CV = 31.3%
5/a 100 ha	6 10/68	10.2 me/100 g s = ±1.92 CV = 18.7%	6.25 me/100 g s = ±1.33 CV = 18.4%	3.78 me/100 g s = ±1.71 CV = 45%
5/b 100 ha	6 10/71	14.5 me/100 g s = ±3.72 CV = 25.5%	10.86 me/100 g s = ±3.86 CV = 35.4%	3.79 me/100 g s = ±2.16 CV = 57%

Conclusion

The accuracy of the determination of soil salinity and alkalinity is influenced first of all by the error of sampling due to the uneven vertical and horizontal distribution of water soluble and exchangeable sodium compounds. To overcome this difficulty a proper sampling plan is necessary. The sampling system should be selected according to the desired accuracy and to the distribution of different salt affected soil types on a complex soil cover. If we know the main factors influencing the horizontal and vertical distribution of water soluble and exchangeable sodium it becomes possible to distinguish the different types of soil populations and to select the proper systems of sampling according to the given type of soil complex.

The salinity and alkalinity status of soil complexes can be characterized and the effects of soil amelioration and irrigation can be determined in the following steps:

Table 9.
The error of sampling and the weighted means of mobile, exchangeable and water soluble sodium on spots of different sizes

No. of spot	Size	Number of profiles	Mobile Na	S_d	Exchangeable Na	S_d	Water soluble Na	S_d
1/a	3.14 m ²	6	$RNa_1 + Na_1 = 11.2$	0.665	$RNa_1 = 9.22$	0.51	$Na_1 = 1.98$	0.39
2/a	0.5 ha	6	$RNa_2 + Na_2 = 11.34$	$t = 0.28$	$RNa_2 = 8.83$	$t = 0.78$	$Na_2 = 2.51$	$t = 1.36$
			$(RNa + Na)_{1-2} = 0.14$		$RNa_1 - RNa_2 = 0.39$		$Na_1 - Na_2 = 0.53$	
1/a	3.14 m ²	6	$RNa_1 + Na_1 = 11.2$	0.88	$RNa_1 = 9.22$	0.715	$Na_1 = 1.98$	0.30
2/b	0.5 ha	6	$RNa_2 + Na_2 = 10.06$	$t = 1.30$	$RNa_2 = 8.18$	$t = 1.71$	$Na_2 = 1.82$	$t = 0.53$
			$(RNa + Na)_{1-2} = 1.14$		$RNa_1 - RNa_2 = 1.04$		$Na_1 - Na_2 = 0.16$	
2/a	0.5 ha	6	$RNa_1 + Na_1 = 11.34$	0.92	$RNa_1 = 8.83$	0.755	$Na_1 = 2.51$	0.35
2/b	0.5 ha	6	$RNa_2 + Na_2 = 10.06$	$t = 1.30$	$RNa_2 = 8.18$	$t = 0.86$	$Na_2 = 1.82$	$t = 1.98$
			$(RNa + Na)_{1-2} = 1.28$		$RNa_1 - RNa_2 = 0.65$		$Na_1 - Na_2 = 0.69$	
1/a	3.14 m ²	6	$RNa_1 + Na_1 = 11.2$	0.6	$RNa_1 = 9.22$	0.624	$Na_1 = 1.98$	0.376
4	1 ha	12	$(RNa + Na)_{1-2} = 12.35$	$t = 1.91$	$RNa_2 = 10.18$	$t = 1.57$	$Na_2 = 2.17$	$t = 0.55$
			$(RNa + Na)_{1-2} = 1.15$		$RNa_1 - RNa_2 = 0.96$		$Na_1 - Na_2 = 0.19$	
1/a	3.14 m ²	6	$RNa_1 + Na_1 = 11.2$	1.65	$RNa_1 = 9.22$	1.5	$Na_1 = 1.98$	0.92
5/b	100 ha	6	$RNa_2 + Na_2 = 14.5$	$t = 2.0$	$RNa_2 = 10.86$	$t = 1.1$	$Na_2 = 3.79$	$t = 1.96$
			$(RNa + Na)_{1-2} = -3.3$		$RNa_1 - RNa_2 = -1.04$		$Na_1 - Na_2 = -1.81$	
4	1 ha	12	$RNa_1 + Na_1 = 12.35$	1.24	$RNa_1 = 10.18$	1.26	$Na_1 = 2.17$	0.85
5/b	100 ha	6	$RNa_2 + Na_2 = 14.50$	$t = 1.73$	$RNa_2 = 10.86$	$t = 0.54$	$Na_2 = 3.79$	$t = 1.90$
			$(RNa + Na)_{1-2} = -2.15$		$RNa_1 + RNa_2 = -0.68$		$Na_1 - Na_2 = -1.62$	
5/a	100 ha	6 68/10	$RNa_1 + Na_1 = 10.2$	1.72	$RNa_1 = 6.26$	1.60	$Na_1 = 3.78$	1.37
5/b	100 ha	6 71/10	$RNa_2 + Na_2 = 14.5$	$t = 2.48^*$	$RNa_2 = 10.86$	$t = 2.75^*$	$Na_2 = 3.79$	
			$(RNa - Na)_{2-1} = 4.3$		$RNa_2 - RNa_1 = 4.4$		$Na_2 - Na_1 = 0.02$	

* The difference of means is more than the 95% confidence limit.

1. Field survey of the area to be characterized.
2. Determination of the vertical distribution of exchangeable and water soluble sodium by analysing the samples collected from representative soil profiles.
3. Determination of the type of soil population and of the ratio of the different types of salt affected soils in the given population. For this purpose a different number of profiles must be sampled on spots of various sizes.
4. Calculation of mobile sodium reserves and determination of the optimum size of spots and the optimum number of profiles to be sampled.
5. On spots having the optimum size samples must be collected regularly from the optimum number of profiles for several years in order to observe the effect of soil amelioration and irrigation on the salinity and alkalinity status of the investigated area.

Summary

For our investigations an area covered by the population of sodium carbonate solonchak and sodium carbonate solonchak-solonetz soils was selected. These soils formed under the influence of the mineralized groundwater. Both soil types are dominated by sodium carbonate and bicarbonate in the soil solution and can be characterized by the increased amount of water soluble sodium compounds and the high degree of sodium saturation.

The accumulation of mobile sodium and the quantities of exchangeable sodium showed maximum values in the *B* horizons of the soils. There was, however, a difference in the distribution of soluble sodium. The maximum of water soluble sodium salts occurs at the surface of the solonchak soil and in the *B*₁ horizons of solonchak-solonetz soils.

The investigation of spots of different sizes showed that in the given population of sodium carbonate solonchak and sodium carbonate solonchak-solonetz soils, solonchaks represented 80–85%, while the remaining 15–20 percent of the area was covered by solonchak-solonetz soils.

The same distribution of soils was observed in the cases of sampling spots with sizes of 3.14 m², 0.5 ha, 1 ha. The mean values of mobile sodium reserves were very close and the difference of means was not characteristic on the 95% confidence level. This means that the two types of salt affected soils form microcomplex population on the investigated area.

The values of mobile, exchangeable and water soluble sodium reserves in the 0–50 cm layers were also very close to each other in the case of all spots. The variation coefficient increased only very slowly with the increase of the size of the sampled spot. The differences of the means of mobile sodium reserves calculated for spots of different sizes and from different numbers of sampled profiles were within the 95% confidence interval. The similar values of mobile sodium reserves show that the sodium compounds are distributed uniformly on the total sampled area. This seems to indicate that if soils having different degrees of salinity and alkalinity form microcomplex population, the mean of mobile sodium reserves measured in a relatively small number of randomly distributed soil profiles is characteristic of a relatively large spot or area with good accuracy. In the investigated area, due to the influence of the high level of mineralized groundwater and to the prevalence of sodium carbonate and

bicarbonate in the soil solution, progressive alkalization of soils is indicated. The increase of the amounts of mobile and exchangeable sodium can be determined by the sampling of the same profiles in the same seasons for several years.

References

- [1] HAMMOND, L. C., PRITCHETT, W. L. & CHEW, W.: Soil sampling in relation to soil heterogeneity. *Soil Sci. Soc. Amer. Proc.* **22**. 548—552. 1958.
- [2] KOSLOVSKY, F. I.: (A structure-functional and mathematical model of migration landscape-geochemical processes). (Russ.) (4) 122—138. 1972.
- [3] PETERSEN, R. G. & CALVIN, L. D.: Sampling. In *Methods of Soil Analysis. Part 2.* (Ed. C. A. Black) 54—72. Amer. Soc. Agron. Madison. 1965.
- [4] SAYEGH, R. G., ALBAN, L. A. & PETERSEN, R. G.: A sampling study in a saline and alkali area. *Soil Sci. Soc. Amer. Proc.* **22**. 252—254. 1958.
- [5] SIGMOND, A. A. J. DE: A békéscsabai öntözött szikes réten végzett sómeghatározásokról. (On the determination of salts of the irrigated alkali meadow at Békéscsaba). *Kísérletügyi Közlem.* **5**. (1) 47—69. 1902.
- [6] SIGMOND, A. A. J. DE: Újabb tapasztalatok a szikes talajról. (New experiences concerning "szik" soils). *Kísérletügyi Közlem.* **6**. (2) 81—120. 1903.
- [7] SIGMOND, A. A. J. DE: Über die Grundfragen in der Zubereitung der Bodenlösungen für die chemische Analyse. *Verh. II. Internat. Agrogeologenkonferenz. Stockholm.* 71—92. 1910.
- [8] SIGMOND, A. A. J. DE: A hazai szikesek és megjavítási módjaik. (Hungarian alkali soils and their reclamation). *Magyar Tud. Akadémia. Budapest.* 1923.
- [9] SIGMOND, A. A. J. DE: General principles for surveying the salty and alkali soils. *Proc. 1st Internat. Congr. Soil Sci. Washington.* **5**. 479—482. 1928.
- [10] SZABOLCS, I.: The influence of sodium carbonate on soil forming processes and on soil properties. *Agrokémia és Talajtan.* **18**. Suppl. 37—68. 1969.
- [11] SZABOLCS, I. & DARAB, K.: Az oldható sók dinamikája öntözött talajokban. (Dynamics of soluble salts in irrigated soils). *Agrokémia és Talajtan.* **4**. 251—259. 1955.