

Natural Leaching Processes in Some Salt-Affected Soils of California

P. JANITZKY and L. D. WHITTIG

*Department of Soils and Plant Nutrition, University of California,
Davis, California, USA*

Study of salt-affected soils is very often restricted to the pedon with unique morphological features or to the individual whose chemical properties require application of reclamation practices for crop production. As further information is gained regarding the characteristics of such soils, it becomes increasingly clear that they must be examined as integral units in a sequential association of several individuals if their complexities are to be understood. Classification of these soils and understanding of genetic processes involved in their development require that they be considered in relation to their position in the present landscape and with regard to their past as well as present environment. Definition of presently or previously salt-affected soils requires a knowledge of each stage during salt accumulation or leaching as the case may be.

The importance of biological formation of NaHCO_3 and Na_2CO_3 and attendant processes involved in development of soil alkalinity have recently been stressed by WHITTIG and JANITZKY [14] in California and by ABD-EL-MALEK and RIZK [1] in Egypt. In these two publications, local accumulations of biologically-induced Na_2CO_3 were manifest. JANITZKY [8], more recently, has described more extended manifestation of similar processes of alkalization and salinization over rather broad areas in the Sacramento Valley, California.

The present paper relates the chemical changes induced by natural leaching of previously salinized soils since removal from the sphere of salinization.

Soils investigated

Two sequences of five profiles each were selected from different localities in the Sacramento Valley. Each sequence includes a range from undifferentiated saline soil to leached soil with characteristic solonetzic morphology. Profiles selected within each sequence represent evident phases in which specific characteristics display a distinct similarity and vary in a definite order and direction as a function of leaching intensity.

The first profile sequence is situated on a gently sloping alluvial fan (less than 1% slope) in eastern Solano County. The sequence is adjacent to a formerly inundated floodplain of a tributary of the Sacramento River. The last, leached profile in the sequence is located approximately one kilometer upslope from the first, saline profile and the remaining profiles lie approxima-

tely in a straight line between the two extremes. The first profile in the sequence represents the position of maximum salt accumulation in the salinization sequence described by JANITZKY [8].

The second profile sequence is situated on a gently sloping alluvial fan (less than 1% slope) in the vicinity of a tidal marsh in western Solano County. The first and last profile in the sequence are separated by a distance of approximately 300 meters.

Since the objective of the present study has been to follow chemical changes resulting from natural leaching of the soils, details of profile morphology will not be presented. However, for the purpose of orientation and to emphasize clearly the role of leaching in the changes observed, brief general description of significant features of the end member profiles and some pertinent field observations are in order.

The saline end member profile in each sequence contains soluble salts throughout and exhibits very little if any textural or structural differentiation. The color of the horizons varies from yellowish-brown near the bottom to olive-gray or gray with proximity to the surface. Mottling is prominent throughout the profiles. The surface in each case is practically devoid of vegetation.

The leached end member profile in each sequence contains very little soluble salts in the A-horizons, but the salts increase in the B and C-horizons. There is an abrupt morphological separation between the leached, sandy loam A-horizons and the prismatic, clay loam B-horizons. The colours vary from pale brown in the A to yellowish-brown in the B-horizons and mottling is evident throughout the B-horizons. These soils support a dense cover of grass vegetation.

The intermediate profiles in each sequence vary in morphological features progressively from the undifferentiated, saline end member to the sharply differentiated, leached end member.

Surface runoff water normally covers the lowest, saline profile in Sequence I and the first two profiles in Sequence II following periods of heavy rainfall during the winter season. Actual ground-water level under other profiles of Sequence I was not encountered at the depth of sampling (approximately 1.5 meters) even during the rainy season. The ground-water level rises to within approximately one meter from the surface of the higher profiles of Sequence II during the drier seasons.

Field observations suggest that the water regime in these areas has changed quite markedly since deposition of the fan sediments. There appears to have been a general recession of the ground-water level since earlier times. A Solano profile studied earlier (WHITTIG [13]), which is located in the same general vicinity and which is very similar in morphology and chemical properties to the leached profiles of the present sequences, still retains relic column tops of a former columnar B-horizon in the present leached, eluvial A-horizon. Surveys of the areas under investigation, conducted in 1911, show marsh lands over much more extensive areas and within much closer proximity to the present sequences than exist at the present time. Evidence strongly indicates that soils in the area presently affected by leaching have been areas of salt accumulation in the past. Recession of the ground-water due to stream entrenchment or uplift of the land surface has removed some of these soils from a sphere of salt accumulation to one of natural leaching. Further evidence of leaching

effect is exemplified by the marked and very abrupt transition between the A and B-horizons of these soils and by the uniform depth of the leached A-horizon over broad expanses of alluvial soils of the area.

Results and discussion

Analytical methods used for determination of pH, electrical conductivity, soluble and exchangeable ions, cation exchange capacity, and precipitated Ca and Mg-carbonates have been described in previous papers (WHITTIG and JANITZKY [14]; JANITZKY and WHITTIG [8]). Results of analyses are reported in Tables 1. and 2.

Sequence I.

The first profile in the sequence, situated at the lowest position adjacent to the former inundated floodplain, exhibits the maximum salt accumulation. As discussed by JANITZKY [7], NaHCO_3 and other soluble salts have migrated laterally from the former marshy area and have concentrated at this position. Na_2CO_3 and NaHCO_3 entering the system have caused precipitation and inactivation of Ca and Mg as carbonates along the path of the accumulation sequence. Concentrations of Ca and Mg-carbonates are thus relatively high in the profile under discussion (Table 1). The fact that Mg in carbonate form is relatively more soluble than CaCO_3 , together with the fact that soluble Mg^{2+} is present in higher concentrations than Ca^{2+} in the ground-water in the former marsh area, which serves as the reservoir from which laterally moving solutions have emanated, accounts for the fact that carbonate of Mg predominates over carbonate of Ca at this position.

Inactivation of divalent cations as relatively insoluble carbonates has favored adsorption of Na^+ by the exchange complex. Exchangeable Na^+ percentage, high throughout the profile, is at a maximum of 81% between 5 and 18 cm. High exchangeable Na^+ is accompanied by relatively high soluble Na^+ . In contrast, soluble and exchangeable Ca^{2+} and Mg^{2+} are depressed. Soluble Ca^{2+} and Mg^{2+} are highest at the very surface where the pH is 6.1. Sulfate is the dominant soluble anion throughout the profile and is followed in order by Cl^- , HCO_3^- , and CO_3^{2-} . The presence of soluble HCO_3^- and CO_3^{2-} is consistent with the low content of soluble Ca^{2+} and Mg^{2+} and with the high pH throughout most of the profile. The distribution of soluble salts in the soil indicates that accumulation has been dominant over leaching at this position.

The second profile in the sequence shows definite evidence of leaching domination. Soluble salts are present in small amounts throughout, but they increase from very low concentration near the surface to considerably higher concentration at lower depths. Soluble Ca^{2+} is absent and soluble Mg^{2+} and Na^+ are present in concentrations of less than 1 me/100 g above 48 cm. Both Cl^- and CO_3^{2-} are absent above 30 cm and SO_4^{2-} and HCO_3^- are present in only very low concentrations.

Exchangeable Na^+ percentage is much lower throughout the second profile and there is a definite trend toward decreasing exchangeable Na^+

Table
Chemical properties of

Profile No.	Depth (cm)	pH	E. C.* (mmhos/cm)	Ca ²⁺ (me/100 g)		
				soluble	exchang.	as CaCO ₂
1.	0 - 1.5	6.1	46.8	0.7	0.7	3.5
	1.5 - 5	8.4	8.7	0.1	2.4	3.5
	5 - 18	9.1	11.8	0.1	1.6	10.2
	18 - 41	9.5	6.9	—	0.7	5.9
	41 - 56	9.5	5.4	—	0.3	4.6
	56 - 76	9.5	4.7	—	0.3	5.7
	76 - 92	9.5	4.5	—	0.2	6.6
	92 - 114	9.4	3.9	—	0.8	31.3
	125 -	9.3	3.6	—	1.4	90.7
	2.	0 - 2.5	5.8	0.5	—	6.2
2.5 - 10		6.0	0.3	—	7.3	1.8
10 - 30		6.5	0.3	—	6.2	1.2
30 - 48		7.9	1.2	—	4.8	1.0
48 - 69		8.2	3.2	0.1	4.4	4.6
69 - 97		8.2	7.2	0.2	2.7	2.9
97 - 104		8.2	7.7	0.2	2.9	10.1
104 - 130		8.3	7.7	0.2	4.2	103.1
140 -		8.4	5.9	0.1	4.8	100.6
3.	0 - 2.5	5.4	0.8	0.1	4.3	0.1
	2.5 - 15	5.3	0.3	—	4.6	—
	15 - 38	5.7	0.5	—	5.4	2.0
	38 - 50	7.0	2.8	0.1	4.8	1.7
	50 - 69	7.8	4.4	0.1	4.0	4.1
	69 - 97	8.0	6.8	0.2	3.5	4.9
	97 - 110	8.0	8.7	0.2	2.9	6.8
	110 - 135	8.0	8.2	0.2	2.7	6.2
4.	0 - 10	5.6	0.4	—	4.2	—
	10 - 25	5.6	0.2	—	4.6	—
	25 - 40	5.7	0.5	—	2.5	—
	40 - 66	6.9	1.5	—	5.1	1.5
	66 - 91	7.8	4.4	0.1	3.9	2.6
	99 - 112	8.0	8.0	0.2	3.3	10.9
	115 - 135	7.9	9.1	0.2	3.1	10.7
	147 - 165	7.8	5.7	0.2	3.3	2.7
5.	0 - 13	5.2	0.4	—	4.4	—
	13 - 51	5.6	0.3	—	5.7	—
	51 - 56	5.8	0.3	—	4.9	—
	56 - 69	6.3	0.4	—	8.7	3.1
	69 - 89	6.7	0.4	—	8.4	2.1
	97 - 122	7.7	0.6	—	6.8	6.8
	135 - 158	7.8	0.8	—	4.6	1.3
183 -	7.7	1.9	—	3.7	1.4	

* Electrical conductivity.

I.

soils of Sequence I.

Mg ⁺⁺ (me/100 g)			Na ⁺ (me/100g)		Cation exchange capacity (me/100 g)	Exchange- able Na ⁺ %	Anions (me/100 g)			
soluble	exchang.	as MgCO ₃	soluble	exchang.			CO ₃ ²⁻	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻
1.9	0.8	3.1	20.5	3.5	9.8	36	—	0.1	21.7	2.4
0.1	2.6	8.2	9.2	18.8	29.0	65	0.1	0.4	5.7	2.9
0.1	1.4	15.9	16.0	30.0	37.2	81	0.2	0.4	13.1	2.5
—	0.9	20.9	11.2	29.6	40.0	74	1.1	0.6	7.7	3.3
0.1	1.6	23.3	10.6	26.6	34.4	77	1.2	0.6	6.5	3.5
0.1	2.5	29.1	10.1	24.3	32.4	75	1.0	0.5	5.8	3.4
0.1	3.8	26.2	9.6	22.8	30.0	76	1.2	0.6	4.8	3.5
0.1	3.7	36.0	8.7	19.3	29.4	66	1.1	0.6	4.4	3.4
0.1	4.5	44.8	6.6	18.8	25.4	74	0.6	0.6	3.0	2.8
0.1	20.8	—	0.1	0.7	32.0	2	—	0.1	0.1	—
0.1	25.6	—	0.1	1.0	37.2	3	—	0.1	0.1	—
0.1	28.8	—	0.1	1.7	37.8	4	—	0.1	0.1	—
0.1	27.8	0.9	0.7	4.5	38.0	12	—	0.3	0.3	0.3
0.4	24.6	3.8	2.2	7.2	37.2	19	—	0.3	1.4	1.1
1.2	23.1	6.1	5.3	8.7	35.6	24	—	0.2	3.7	2.6
1.4	21.5	1.0	5.3	8.8	33.6	26	—	0.2	4.2	2.7
1.3	18.2	30.0	5.2	8.3	30.4	27	—	0.1	3.8	2.7
0.7	17.5	23.8	5.4	8.3	30.0	28	—	0.1	2.5	2.5
0.2	8.9	—	0.1	0.7	19.4	4	—	0.1	0.1	0.1
—	10.3	—	—	0.8	19.4	4	—	—	—	—
0.1	20.1	—	0.1	1.6	28.6	6	—	—	0.1	0.1
0.3	19.1	—	1.2	4.4	27.8	16	—	0.1	0.2	1.2
0.5	19.5	—	2.3	5.7	28.0	20	—	0.1	0.4	2.4
1.0	19.2	—	3.7	6.1	28.6	21	—	0.1	0.7	3.8
1.5	17.2	1.9	4.1	5.6	24.8	22	—	0.1	0.9	4.9
1.2	15.7	—	3.4	4.7	22.6	21	—	0.1	0.3	4.2
0.1	5.1	—	—	0.5	13.6	4	—	0.1	—	—
—	5.7	—	—	0.5	12.4	4	—	—	—	—
—	5.8	—	0.1	1.1	11.0	10	—	—	—	0.1
0.1	17.5	—	0.8	4.7	27.2	17	—	—	—	0.9
0.4	18.3	—	2.3	5.5	26.0	21	—	—	0.1	2.8
1.4	16.3	5.8	4.3	4.8	24.2	20	—	0.1	0.3	5.6
1.3	13.9	—	3.4	4.5	20.6	22	—	0.1	0.1	4.7
0.8	16.7	—	2.4	4.6	24.0	19	—	0.1	0.1	3.2
—	2.8	—	—	0.4	14.7	3	—	—	—	—
—	4.2	—	—	0.4	13.7	3	—	—	—	—
—	5.2	—	—	0.5	12.2	4	—	—	—	—
—	11.6	—	0.1	0.9	22.6	4	—	—	—	0.1
—	11.2	—	0.1	1.2	22.2	5	—	—	—	0.1
—	8.9	—	0.2	1.6	18.6	9	—	0.1	—	0.1
—	7.4	0.1	0.2	2.2	14.2	15	—	—	—	0.2
—	6.4	—	0.5	2.2	12.6	17	—	—	0.2	0.3

Table
Chemical properties of

Profile No.	Depth (cm)	pH	E. C.* (mmhos/cm)	Ca ²⁺ (me/100 g)		
				soluble	exchang.	as CaCO ₃
1.	0-3	7.2	31.4	1.6	3.9	6.3
	3-13	7.6	21.4	0.4	3.2	5.6
	13-30	8.0	19.5	0.4	2.8	13.8
	30-51	8.2	22.3	0.8	3.1	75.4
	51-68	8.3	21.2	0.8	3.2	116.5
	68-94	8.3	20.1	0.8	1.9	131.2
	94-140	8.3	18.8	0.5	1.9	114.5
Ground-water (me/liter)	100	7.2		49.3		
2.	0-9	6.6	6.1	0.4	6.8	16.5
	9-13	7.6	7.2	0.2	6.6	17.4
	13-26	7.9	11.2	0.5	5.7	23.1
	26-36	8.0	10.6	0.5	5.0	42.9
	36-50	8.2	15.5	0.8	5.1	175.4
	50-74	8.3	16.1	0.8	4.9	77.4
	74-115	8.1	20.1	1.1	3.8	64.5
115-160	8.1	23.7	1.1	3.0	252.3	
Ground-water (me/liter)	66	7.1		102.2		
3.	0-10	5.1	1.9	—	2.5	1.6
	10-30	7.0	4.6	—	5.6	5.2
	30-40	7.5	8.7	0.3	4.2	5.3
	40-66	7.7	10.1	0.3	4.2	6.8
	66-120	8.0	12.8	0.7	4.5	42.7
	120-145	8.0	13.9	0.8	5.9	83.4
Ground-water (me/liter)	80	6.8		106.9		
4.	0-13	4.8	0.6	—	0.7	2.1
	13-30	4.8	1.0	—	0.3	1.7
	30-38	5.2	4.8	0.1	3.1	4.0
	38-42	6.5	5.2	0.1	4.2	4.4
	42-53	7.3	7.4	0.2	4.1	6.2
	53-71	7.5	9.6	0.3	9.8	5.2
	71-84	7.9	13.4	0.8	8.7	49.7
84-117	8.0	13.1	0.7	8.8	89.9	
117-148	7.9	13.0	0.6	4.9	57.8	
Ground-water (me/liter)	92	7.2		68.9		
5.	0-13	5.2	1.0	—	1.8	2.5
	13-25	5.2	0.6	—	1.7	2.1
	25-37	5.2	0.4	—	1.5	2.1
	37-46	5.3	0.5	—	2.2	1.1
	46-57	5.3	1.0	—	5.6	3.6
	57-68	6.1	1.8	—	4.6	2.3
	68-74	7.1	1.8	—	4.5	3.5
	74-84	7.8	2.6	—	4.8	3.9
No ground-water at 150 cm depth.	84-100	7.9	2.3	—	5.5	7.3
	100-125	8.0	2.5	—	5.8	11.4

* Electrical conductivity.

2.

soils of Sequence II.

Mg ²⁺ (me/100 g)			Na ⁺ (mc/100g)		Cation exchange capacity (mc/100 g)	Exchange- able Na ⁺ %	Anions (me/100 g)			
soluble	exchang.	as MgCO ₃	soluble	exchang.			CO ₃ ²⁻	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻
3.3	6.0	4.6	14.8	7.8	21.3	37	—	—	0.9	20.6
1.2	8.9	2.3	11.7	7.4	24.3	30	—	0.1	0.8	13.4
1.3	8.8	7.4	12.6	8.3	25.2	33	—	0.1	0.9	15.1
1.8	8.2	19.3	15.2	8.3	23.9	35	—	0.2	0.9	18.1
1.9	7.9	26.2	17.4	7.8	23.9	33	0.1	0.1	1.0	20.6
1.7	7.7	32.8	16.7	7.6	22.6	34	0.1	0.1	0.9	19.8
1.3	7.7	28.6	14.3	10.9	21.3	51	0.1	0.1	0.8	15.0
135.4			608.7				—	5.5	27.5	756.9
0.6	7.1	12.9	2.5	2.3	20.0	11	—	—	0.2	3.5
0.5	7.7	13.9	3.9	5.7	23.9	24	—	0.1	0.5	4.5
0.8	8.4	17.0	7.4	6.5	25.2	26	—	0.1	1.1	9.3
0.8	8.5	21.6	7.7	8.0	24.8	32	—	0.1	1.0	8.5
1.1	8.0	35.7	9.3	8.5	23.9	36	—	0.1	1.1	10.7
1.4	8.5	15.0	10.6	9.8	25.2	39	—	0.1	1.1	12.5
1.8	9.4	10.2	12.5	12.7	28.3	45	—	0.1	1.3	15.1
1.7	5.1	16.3	10.4	7.0	14.8	47	—	0.1	0.8	12.9
174.8			586.9				—	4.6	43.8	818.5
0.1	3.1	—	0.4	1.0	9.6	10	—	—	—	0.5
0.3	8.8	0.7	2.1	5.3	24.3	22	—	0.1	0.2	2.3
0.5	8.2	3.1	5.2	7.8	25.7	30	—	0.1	0.4	5.7
0.8	8.6	1.4	8.1	11.0	29.1	38	—	0.1	0.5	9.0
1.2	9.2	3.5	10.0	14.3	34.3	42	—	0.1	0.5	11.8
1.3	9.2	7.5	11.3	15.2	36.1	42	—	0.1	0.4	13.5
177.6			630.4				—	3.0	25.2	890.3
0.1	1.7	—	0.1	0.2	7.4	3	—	—	0.1	0.1
0.1	1.4	—	0.2	0.4	6.5	6	—	—	0.1	0.2
0.3	5.8	1.1	1.5	2.8	17.4	16	—	—	0.1	2.0
0.3	7.0	0.1	2.0	4.1	19.6	21	—	—	0.1	2.3
0.4	7.7	1.1	3.2	5.9	23.5	25	—	—	0.2	3.8
0.6	7.8	2.1	5.1	6.6	24.8	27	—	—	0.3	6.0
1.2	8.0	4.4	8.2	8.3	27.0	31	—	0.1	0.3	9.9
1.0	8.8	9.2	7.7	11.0	31.3	35	—	0.1	0.3	9.4
0.9	9.8	6.8	7.8	13.9	36.5	38	—	0.1	0.3	9.6
110.3			369.6				—	2.1	10.1	533.6
0.2	1.2	—	0.1	0.2	6.9	3	—	—	0.1	0.2
0.1	1.1	—	0.1	0.2	6.1	3	—	—	—	0.1
—	1.4	—	0.1	0.3	6.1	5	—	—	—	0.1
—	2.3	0.5	0.1	0.4	6.1	7	—	—	—	0.1
—	5.6	0.3	0.3	2.4	16.1	15	—	—	—	0.3
—	4.9	0.7	0.4	2.7	12.6	21	—	—	—	0.4
—	5.0	0.4	0.4	3.8	13.5	28	—	—	—	0.4
0.1	5.1	0.7	0.6	3.6	13.9	26	—	—	0.1	0.6
0.1	6.9	0.7	0.7	5.2	19.1	27	—	0.1	0.1	0.6
0.1	6.9	2.0	1.0	5.6	19.6	29	—	0.1	0.1	0.9

percentage with proximity to the surface. Exchangeable Ca^{2+} , on the other hand, is higher in this profile and is most evident in the upper 69 cm and below 104 cm.

Of particular significance is the dramatic increase in exchangeable Mg^{2+} in this profile as compared to the first. Whereas the exchangeable Mg^{2+} varies from 17.5 me/100 g below 140 cm to as high as 28.8 me/100 g between 10 and 30 cm, the maximum was only 7.5 me/100 g below 125 cm in the first profile. Consistent with the increase in exchangeable Mg^{2+} , precipitated Mg decreases markedly from the lower horizons upward. No Mg as carbonate remains above 30 cm.

Initiation of leaching has decreased soluble salt concentration markedly within this soil, especially near the surface. Removal of soluble CO_3^{2-} and HCO_3^- has resulted in lower pH and increase in solubility of precipitated carbonates, particularly Mg. With increase in Mg^{2+} activity, Na^+ has been readily replaced from the exchange complex by Mg^{2+} and has been leached from the profile. Whereas carbonate of Mg is present in greater quantity than carbonate of Ca throughout most of the first profile, the relative abundance of the two components is reversed in the second profile.

The third and fourth profiles in the sequence illustrate more advanced phases of leaching as exemplified by lower concentrations of soluble salts, lower pH, virtual absence of precipitated Mg and considerably smaller quantities of precipitated Ca, especially near the surface. In profile 4, soluble Na^+ , Ca^{2+} , Mg^{2+} , HCO_3^- , CO_3^{2-} , SO_4^{2-} , and Cl^- are absent in the upper horizons but are still present in relatively small concentrations in lower horizons.

The last profile in the sequence is essentially free of soluble salts with the exception of a small amount of NaCl in the lower horizons. Precipitated Mg is gone and precipitated Ca is present in the lower horizons only in small quantities. Persistence of Ca^{2+} after removal of Mg^{2+} reflects the difference in solubility of the two components during leaching.

It is significant that exchangeable Ca^{2+} is generally higher in the last profile than in the preceding ones and that exchangeable Mg^{2+} has decreased generally from profile 2. to profile 5. The Mg^{2+} which entered the exchange complex early in the leaching cycle has slowly been replaced by Ca^{2+} from less soluble CaCO_3 and by H^+ through hydrolysis. The acid, upper horizons undoubtedly contain appreciable exchangeable H^+ .

Sequence II.

Soils in the second sequence have been influenced by relatively high concentrations of NaCl (Table 2.). The ground-water which rises to within one meter or less of the surface of the first four profiles during the rainy season contains up to 630 me Na^+ and 890 me Cl^- per liter (under profile 3.). It carries lesser, yet relatively high, concentrations of Mg^{2+} , Ca^{2+} , and SO_4^{2-} and relatively low concentrations of HCO_3^- .

As might be expected from the composition of the ground-waters, exchangeable Na^+ percentage is relatively high throughout the first three profiles and in lower horizons of the last two profiles of the sequence. Exchangeable Na^+ percentage is at a lower level in the first profile, however, than in the first profile of Sequence I. Exchangeable Mg^{2+} and Ca^{2+} , on the other hand,

are higher in the first profile of this sequence. Distribution of exchangeable cations in the first, saline profile is a reflection of the concentration of soluble ions in the ground-water and of the relative adsorptive capacity for the ions involved.

Despite initial differences in the saline end members of the two sequences, chemical changes induced by leaching have been similar in both vertical and horizontal dimensions.

Both soluble cations and soluble anions decrease in concentration with proximity to the surface in all but the lowest, non-leached profile in the sequence, and there is a general decrease in concentration of soluble salts progressing from the lowest to the highest profile. Exchangeable Na^+ , relatively uniform in distribution throughout the first profile, shows a progressive decrease with proximity to the surface in the remaining profiles and the depth to which Na^+ decrease is manifest increases progressively from profile 2. through profile 5. Concomitant with decrease in exchangeable Na^+ in the leached portion of profile 2. is an increase in exchangeable Mg^{2+} and Ca^{2+} which again, as in Sequence I, reflects solubilization of precipitated carbonates of Ca and Mg during leaching. In succeeding profiles in the sequence, exchangeable Mg^{2+} and Ca^{2+} show a concentration distribution pattern similar to that exhibited by Na^+ . This is attributed to the influence of hydrolysis and entrance of H^+ ion into the exchange equilibrium as a result of leaching. Influence of H^+ is reflected by the low pH exhibited by the leached portions of the profiles (as low as 4.8 above 30 cm in profile 4.).

The magnitude of chemical changes induced by leaching in Sequence II is generally less than displayed in Sequence I. This is attributed to the fact that soils in Sequence II are still affected by relatively high ground-water levels during part of the year, which partially reverses or represses the change induced by the predominant influence of leaching.

Conclusions

Evaluation of effects of natural leaching of saline-sodic soils in the two sequences studied leads to several rather definite conclusions.

Leaching of these soils has proceeded in a regular and consistent manner regardless of differences in initial salt concentration and composition. Removal of soluble and exchangeable Na^+ is accomplished early in the leaching cycle. Decrease in exchangeable Na^+ is greatly accelerated by solubilization of Mg^{2+} and Ca^{2+} , present in these soils as precipitated carbonates, and their subsequent entry into the exchange complex.

The role of Mg^{2+} during solonization and solodization of salt affected soils and its source has received considerable attention. ROST and MAEHL [12] and ELLIS and CALDWELL [5] have suggested that Mg^{2+} may be responsible for dispersion of clay in solonized soils. RIECKEN [11] and BARSHAD [2] have suggested that the presence of Mg^{2+} ions in high proportions in many solonetzic soils is due to release of Mg^{2+} by weathering of Mg-bearing minerals during the soils' evolution. Data obtained in the present study indicate that the Mg^{2+} and Ca^{2+} evolve by solubilization of precipitated carbonates of the two bases during leaching, as suggested earlier for similar soils by KELLEY [9] and WHITTIG [13], and that replacement of adsorbed Na^+ by Mg^{2+} and Ca^{2+}

occurs early in the leaching cycle. The relatively high exchangeable Mg^{2+} in these leached soils, which also display morphological features of solonetz, gives them properties similar to the so-called Mg-solonetz. The question regarding the possible relationship between Mg^{2+} and development of solonetzic morphology is not clear and is the subject of further investigation.

Replacement of Na^+ by divalent cations does not lead to accumulation of Na_2CO_3 in the soils studied. Under the influence of leaching, soluble CO_3^{2-} has been removed at a faster rate than have the other soluble anions such as Cl^- and SO_4^{2-} . Development of appreciable alkalinity as a result of hydrolysis of Na-clay under the influence of active leaching, a mechanism suggested by GEDROIC [6], CUMMINS and KELLEY [4], CUMMINS [3], and KELLEY [10] would appear to be of small significance, or possibly of a transitory nature, in soils containing Ca or Mg carbonates.

References

- [1] ABD-EL-MALEK, Y. & RIZK, S. G.: Bacterial sulphate reduction and the development of alkalinity. *J. Appl. Bacteriol.* **26**. 7—26. 1963.
- [2] BARSHAD, I.: Significance of the presence of exchangeable magnesium ions in acidified clays. *Science*. **131**. 988—990. 1960.
- [3] CUMMINS, A. B.: The solubility relationships of calcium carbonate with special reference to the formation of sodium carbonate in soils. Ph. D. thesis. University of California. 1926.
- [4] CUMMINS, A. B. & KELLEY, W. P.: The formation of sodium carbonate in soils. *Calif. Agr. Expt. Sta. Techn. Paper*. **3**. 1—35. 1923.
- [5] ELLIS, J. H. & CALDWELL, O. G.: Magnesium clay solonetz. *Trans. Internat. Congr. Soil Sci. 3rd Congr. Oxford*. **1**. 348—350. 1935.
- [6] GEDROIC, K. K.: Colloidal chemistry as related to soil science. I. Colloidal substances in the soil solution. Formation of sodium carbonate in the soil. *Zhurn. Opyt. Agron.* **13**. 363—412. 1912.
- [7] JANITZKY, P.: Biologically induced soil alkalinity. *Trans. Internat. Congr. Soil Sci. 8th Congr.* 1964. (In press.)
- [8] JANITZKY, P. & WHITTIG, L. D.: Mechanisms of formation of sodium carbonate in soils: II. Laboratory study of biogenesis. *J. Soil Sci.* **15**. 145—157. 1964.
- [9] KELLEY, W. P.: Alkali soils, their formation, properties and reclamation. Reinhold. New York. 1951.
- [10] KELLEY, W. P.: Sodium carbonate and adsorbed sodium in semiarid soils. *Soil Sci.* **94**. 1—5. 1962.
- [11] RIECKEN, F. F.: Some considerations in the magnesium cycle of weathering in solonetz soils. *Soil Sci. Soc. Amer. Proc.* **8**. 391—395. 1944.
- [12] ROST, C. O. & MÄHNL, K. A.: Some solodized soils of the Red River Valley. *Soil Sci.* **55**. 301—312. 1943.
- [13] WHITTIG, L. D.: Characteristics and genesis of a solodized-solonetz of California. *Soil Sci. Soc. Amer. Proc.* **23**. 469—473. 1959.
- [14] WHITTIG, L. D. & JANITZKY, P.: Mechanisms of formation of sodium carbonate in soils: I. Manifestation of biological conversions. *J. Soil Sci.* **14**. 322—333. 1963.

Естественные процессы выщелачивания в некоторых засоленных почвах Калифорнии

ЯНИЦКИЙ, П. и ВИТТИГ, Л. Д.

Отдел Почвоведения и Питания Растений Калифорнийского Университета, Девис, Калифорния, США

Резюме

Съёмка засоленных почв в Калифорнии редко простиралась за пределы морфологических описаний или частичных химических анализов в практических целях мелиорации. Отсутствие полноценных данных о легкорастворимых солях и обменных основаниях в одной и той же почве, равно как и в почвах, характерных для определенного ландшафта, вызывает трудности при решении вопросов генетического порядка.

В целях лучшего ознакомления с развитием некоторых типичных засоленных почв Калифорнии, некоторые профили рассматривались как фазы некоего ряда почв, в котором определенные свойства должны обнаруживать либо сходство, либо изменение в закономерном порядке и направлении.

Два таких ряда почв были выбраны из разных местностей. Каждый включает в себе полный диапазон от солончака со слабо развитыми морфологическими признаками до промытой почвы с сильной дифференциацией профиля. Исходные состояния в обоих рядах значительно отличаются друг от друга реакцией, количеством и составом солей и обменных оснований.

В первом ряду, расположенном неподалеку от крайне засоленных приморских болот, обнаружена относительно высокая концентрация нейтральных солей, особенно NaCl. Количество обменного Na⁺ увеличивается с первых же стадий выщелачивания прогрессивно от верхних горизонтов к нижним частям почвы в каждом профиле ряда. Абсолютная концентрация его однако постепенно уменьшается в соответствующих слоях с дальнейшим выщелачиванием, вытесняясь в основном Ca²⁺.

Количество обменного Mg²⁺ остается постоянно высоким через все горизонты во всех профилях, независимо от реакции или количества солей. Только в последних двух профилях его концентрация слегка понижается у поверхности, вследствие обмена на H⁺ или Ca²⁺.

Обменный Ca²⁺ отражает гораздо сильнее, чем Mg²⁺, влияние процесса вымывания тем, что количества его в значительной мере колеблются либо в связи с нарастающей кислотностью в элювиальных горизонтах, либо за счет увеличивающегося количества обменного Na⁺ в нижних слоях. Количество Ca²⁺ достигает равномерно высоких величин только в самом последнем профиле, в котором солеустойчивая растительность предыдущих профилей вытеснена густым травяным покровом.

Заслуживает внимания то обстоятельство, что процесс выщелачивания в этом ряду протекает на фоне почти полного отсутствия ионов HCO₃⁻ + CO₃²⁻. Обменный Na⁺ удаляется из верхних горизонтов почти одновременно с Na⁺ без ожидаемых последствий гидролиза.

Второй ряд почв расположен на внутренних пространствах штата в долине реки Сакраменто в нижнем ее течении, куда соли привносятся водами из окружающих районов. Биохимические реакции, происходящие в пониженных частях местности и описанные в другом месте, привели к сильному накоплению легкорастворимых карбонатов в первом профиле. Реакция достигает значительно больших величин, нежели в соответствующей почве первого ряда. Общая исходная концентрация солей однако гораздо ниже. Несмотря на это, почва в гораздо большей степени насыщена Na⁺, т. е. отношение Na⁺ к Ca²⁺ + Mg²⁺ в растворе превышает в верхнем горизонте приблиз. в 15 раз это же отношение в первой почве предыдущего ряда. Обменный Mg²⁺ в значительной мере подавлен, а количество обменного Ca²⁺ уменьшается с возрастающей глубиной до незначительных величин.

Вопреки таким большим расхождениям в исходных почвах обоих рядов, процесс выщелачивания приводит к почти тождественным изменениям как в вертикальном, так и в горизонтальном направлении. Концентрация HCO₃⁻ + CO₃²⁻ понижается с такой же быстротой как и количество обменного Na⁺. Количество Ca²⁺ медленно возрастает в верхней части профилей по мере снижения pH. Mg²⁺ является господствующим обменным ионом во всех профилях, находящихся в стадии выщелачивания. Абсолютные его концентрации достигают еще более высоких величин, чем в первом ряду. Эта последователь-

ность в поведении Mg^{2+} в течение процесса выщелачивания засоленных почв является предметом дальнейших исследований вопросов, касающихся так наз. магниевго солонца.

Следующие выводы можно сделать из полученных данных: 1. Процесс в разных видах засоленных почв протекает в весьма закономерном и последовательном порядке, независимо от исходного количества и состава солей. 2. Удаление Na^+ не вызывает образования Na_2CO_3 . В тех случаях, когда эта соль накопилась в течение более ранних стадий почвообразования, она вымывается гораздо быстрее, чем другие легкорастворимые соли. 3. В какой форме присутствуют двухвалентные катионы, прежде чем почва подвергается выщелачиванию — этот вопрос является второстепенным. Даже будучи осажденными в виде карбонатов, они относительно быстро поступают в раствор, особенно Mg^{2+} , и вытесняют обменный Na^+ без заметного увеличения количества $HCO_3^- + CO_3^{2-}$. 4. Действительный гидролиз Na , приводящий к образованию $NaOH$ и Na_2CO_3 в течение промывания, возможен очевидно только при полном отсутствии Ca^{2+} и Mg^{2+} в почве, что представляется сомнительным в естественных условиях.