STUDIES ON SALINE, SALINE-ALKALI AND ALKALI SOILS

I. Classification of Salt-affected Soils in the Vicinity of Allahabad

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Seven complete soil profiles were collected from different places of Allahabad and Fatehpur districts of Uttar Pradesh and some physical and chemical properties were studied. The profiles fall into three categories: (1) Saline (Ghurpur profile); (2) Saline-alkali (Handia, Katoghan and Soraon profiles); (3) Non-saline alkali (Phulpur, Meja and Chial profiles). This classification of soils is based on their contents of exchangeable sodium percentages (E.S.P.) and total soluble salts. Except Ghurpur profile, the rest of profiles contain a zone of $CaCO_3$ accumulation at varying depths. The profiles vary in their Cl^- and SO_4^{2-} contents to a great extent.

In recent years large area of cultivable land of Allahabad and adjoining districts has considerably deteriorated due to accumulation of soluble salts on the surface of soils. These salts are white to black depending upon the elevation of the land. In order to assess the nature of such salt-infested soils, seven complete soil profiles were collected from different places of Allahabad and Fatehpur districts of Uttar Pradesh. The results regarding the physico-chemical characteristics of these soils have been reported in this paper.

Experimental Procedure

The soils used in the present investigation were collected from different places of Allahabad and Fatehpur districts of Uttar Pradesh. The soil of each horizon was air-dried, powdered and finally passed through a 100 mm sieve. They were analysed for *p*H (1:2·5, soil:water extract) by a glass electrode *p*H meter (Jackson 1962). Electrical conductivity (E.C.) was determined in soil:water (1:1) extract by a Leeds and Northrup's conductivity bridge (Wilcox 1950). Sodium and potassium were estimated by a flame photometer using oxygen-acetylene flame at 589 and 767 $m\mu$ respectively. The soluble salts were determined in soil:water (1:5) extract by shaking 20 g of different soils into 100 ml of distilled water in a stoppered 500-ml conical flask. The anions, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-}, etc., were determined by standard methods outlined in the U.S. Salinity Laboratory Manual (1954).

Exchangeable cations were determined in ammonium acetate extract of soils and cation exchange capacity by distilling off absorbed ammonia in standard 0·1 HCl (Barrows and Drosodoff 1958).

Results and Discussion

Ghurpur Profile

This profile can be classified as saline profile because E.C. is more than 4·0 mmhos/cm and E.S.P. is less than 15. The *p*H in this profile does not exceed 8·5. The maximum content of $CaCO_3$ is only 2·25 per cent in the bottom layer. Among the four cations present, Na^+ is in high amounts. Cl^- and SO_4^{2-} are the main anions. These are present to an extent of 0·2 and 0·25 per cent respectively in the surface layer of the profile. Ca^{2+} appears to be the dominant exchangeable cation, recording a value of 6·01 m.e./100 g in the first layer (Table I).

Table I

Analysis of the soil extract (1 : 5 soil : water)

Horizons (cm)	*p*H	$CaCO_3$ (%)	E.C. $\times 10^3$	Cations				Anions			
				Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
0–7	8·2	1·75	10·5	0·082	0·029	0·094	0·012	—	0·043	0·210	0·250
7–37	7·8	1·50	7·5	0·060	0·026	0·070	0·018	—	0·028	0·180	0·220
37–67	8·2	1·37	7·2	0·066	0·028	0·085	0·009	—	0·012	0·170	0·080
67–97	8·0	1·87	6·2	0·061	0·017	0·065	0·008	—	0·092	0·140	0·120
97–125	8·4	2·25	5·2	0·058	0·015	0·068	0·005	—	0·096	0·140	0·150

Exchangeable cations

Horizons (cm)	C.E.C. (m.e./100 g)	Exchangeable cations, m.e./100 g				S.A.R.	E.S.P.
		Ca^{2+}	Mg^{2+}	Na^+	K^+		
0–7	10·50	6·01	2·10	1·10	0·17	18·28	20·38
7–37	10·0	4·10	1·75	0·72	0·15	17·33	19·50
37–67	12·0	4·20	1·82	0·65	0·16	16·11	18·31
67–97	12·2	4·15	1·66	0·53	—	12·39	14·50
97–125	11·0	3·50	1·40	0·43	—	12·06	14·14

Handia Profile

It appears from Table II that all the layers of the profile are highly alkaline, there being tendency for gradual drop in *p*H from the first to the last layer. Percentage of alkaline earth carbonates ($CaCO_3$) increases from 15·10 to 23·0 per cent in the first to the last layer. Soluble Na^+ is quite high,

0·072 per cent in the surface layer and shows gradual decrease up to the third layer below which it has increased slightly. HCO_3^- is extremely high in the profile, followed by CO_3^{2-}. Exchangeable Na^+ constitutes over 50·0 per cent of the exchangeable cations. Exchangeable Ca^{2+} is also in fairly good amount. E.S.P. varies between 36·88 and 51·46.

TABLE II

Analysis of the soil extract (1 : 5, soil : water)

Horizons (cm)	*p*H	$CaCO_3$ (%)	E.C. $\times 10^3$	Cations (%)				Anions (%)			
				Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
0–10	10·4	15·1	5·0	0·034	0·010	0·072	0·006	0·31	0·70	0·026	0·02
10–40	10·1	18·52	4·1	0·032	0·012	0·068	0·008	0·22	0·64	0·017	0·03
40–70	10·0	22·5	4·5	0·031	0·012	0·046	0·014	0·18	0·62	0·015	0·01
70–85	9·8	22·9	3·8	0·025	0·014	0·059	0·014	0·09	0·42	0·011	0·01
85–125	9·2	23·0	4·8	0·028	0·015	0·043	0·018	0·22	0·66	0·067	0·02

Exchangeable cations

Horizons (cm)	C.E.C. m.e./100 g	Exchangeable cations, m.e./100 g				S.A.R.	E.S.P.
		Ca^{2+}	Mg^{2+}	Na^+	K^+		
0–10	16·1	6·01	2·01	9·30	0·58	60·95	46·90
10–40	11·6	4·10	1·75	6·20	0·37	72·98	51·46
40–70	10·5	4·20	1·75	5·80	0·18	65·92	48·80
70–85	10·2	4·25	1·66	6·27	0·12	51·90	42·85
85–125	10·8	3·70	1·91	4·43	0·20	40·62	36·88

Katoghan Profile

In this profile high *p*H values are noted in the surface layer, whilst accumulation of alkaline earth carbonates is noted in lower horizons, especially in the last layer. E.C. values are quite high. The surface layer shows E.C. equal to 14·1 mmhos/cm. A characteristic feature of this profile is the high content of soluble Na^+ (0·194 per cent) in the surface layer. Soluble Ca^{2+} and Mg^{2+} are in meagre amounts. Among the four anions present, HCO_3^- appears to be dominant, Cl^- is quite low but SO_4^{2-} is present in fairly good amounts. Exchangeable Na^+ is quite high throughout the profile, whilst exchangeable Ca^{2+} and K^+ are quite low. Both S.A.R. and E.S.P. decrease with depth (Table III).

Soraon Profile

The first and second layers of this profile show high *p*H values, indicating that the upper layers are more alkaline. A high content of $CaCO_3$

TABLE III

Analysis of the soil extract (1 : 5, soil : water)

Horizons (cm)	pH	$CaCO_3$ (%)	E.C. $\times 10^3$	Cations (%)				Anions (%)			
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
0–28	10·0	14·5	14·1	0·016	0·021	0·194	0·018	0·087	0·296	0·001	0·02
28–90	9·9	12·0	9·1	0·019	0·015	0·130	0·006	0·021	0·274	0·003	0·06
90–105	9·8	24·2	9·0	0·018	0·013	0·110	0·006	0·024	0·184	0·008	0·04

Exchangeable cations

Horizons (cm)	C.E.C. (m.e./100 g)	Exchangeable cations, m.e./100 g				S.A.R.	E.S.P.
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		
0–28	12·5	4·00	0·82	9·70	0·70	58·36	45·80
28–90	10·2	2·04	1·12	7·50	1·19	41·18	37·21
90–105	14·1	4·50	2·94	7·53	1·59	42·37	37·11

is noted throughout the profile, reaching a value of 18·0 at a depth of 175 cm. Exchangeable Na^{+} constitutes main cation. Ca^{2+} is not high. Surface layer shows 0·158 per cent of soluble Na^{+}. CO_3^{2-} and HCO_3^{-} are the main anions.

TABLE IV

Analysis of the soil extract (1 : 5, soil : water)

Horizons (cm)	pH	$CaCO_3$ (%)	E.C. $\times 10^3$	Cations (%)				Anions (%)			
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
0–25	9·7	13·5	9·4	0·025	0·014	0·158	0·002	0·204	0·219	0·026	0·06
25–75	9·7	12·5	7·3	0·042	0·009	0·186	0·017	0·180	0·154	0·030	0·04
75–100	9·4	15·0	6·1	0·047	0·010	0·123	0·035	0·186	0·164	0·019	0·02
100–150	9·3	16·3	6·5	0·026	0·017	0·120	0·020	0·153	0·162	0·018	0·01
150–175	9·0	18·0	3·5	0·025	0·019	0·098	—	0·024	0·134	0·011	0·008

Exchangeable cations

Horizons (cm)	C.E.C. (m.e./100 g)	Exchangeable cations, m.e./100 g				S.A.R.	E.S.P.
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		
0–25	8·1	2·32	1·00	6·43	0·85	54·41	44·04
25–75	11·2	2·40	1·60	6·80	0·92	48·96	48·42
75–100	13·6	3·40	0·85	7·12	1·10	50·85	42·35
100–150	15·7	3·13	2·10	6·86	1·20	47·54	40·82
150–175	15·5	2·60	3·10	7·75	1·60	31·52	31·01

Na^+ appears to be the main exchangeable cation, other cations being present in low amounts. Exchangeable Na^+ alone accounts for about 50 per cent of the exchangeable cations. S.A.R. and E.S.P. both decrease (only with a slight increase in the third and second layers respectively) with depth whereas C.E.C. goes on increasing with depth (Table IV).

Phulpur Profile

The *p*H values in Phulpur profile mark a regular but slight decline with depth, indicating that the surface soil is more alkaline than the sub-soil. On the other hand, alkaline earth carbonates increase with depth attaining a maximum at a depth of 175 cm. E.C. increases and then decreases in lower horizons. Though Na^+ is predominant exchangeable cation, it decreases with depth, and is followed by Ca^{2+}. Mg^{2+} and K^+ are present in small amounts. CO_3^{2-} and HCO_3^- appear to be main anions. Their amounts in decreasing order can be written as $HCO_3^- > CO_3^{2-} > Cl^- > SO_4^{2-}$. C.E.C. first increases and then decreases. S.A.R. and E.S.P. values go on decreasing with depth (Table V).

TABLE V

Analysis of the soil extract (1 : 5, soil : water)

Horizons (cm)	*p*H	$CaCO_3$ (%)	E.C. $\times 10^3$	Cations (%)				Anions (%)			
				Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
0–5	10·3	8·8	2·7	0·026	0·010	0·068	0·004	0·263	0·028	0·050	0·03
5–25	10·1	8·3	3·0	0·032	0·012	0·063	0·003	0·202	0·300	0·045	0·02
25–50	9·8	9·4	3·5	0·038	0·013	0·065	0·018	0·220	0·350	0·030	0·02
50–75	9·3	19·1	3·1	0·040	0·013	0·055	0·016	0·303	0·400	0·025	0·02
75–100	9·1	15·0	1·5	0·037	0·014	0·045	0·016	0·310	0·450	0·010	0·01
100–155	9·0	16·0	1·4	0·046	0·027	0·052	0·008	0·270	0·500	0·009	0·01
155–175	8·9	18·6	1·8	0·046	0·018	0·050	0·008	0·282	0·520	0·008	0·01
175–185	8·8	17·3	1·7	0·032	0·019	0·048	0·010	0·210	0·550	0·005	0·008

Exchangeable cations

Horizons (cm)	C.E.C. (m.e./100 g)	Exchangeable cations, m.e./100 g				S.A.R.	E.S.P.
		Ca^{2+}	Mg^{2+}	Na^+	K^+		
0–5	12·5	2·80	1·00	10·00	0·15	59·42	46·26
5–25	15·1	2·10	0·84	9·14	0·18	53·19	40·09
25–50	15·8	2·62	1·16	10·80	0·27	51·01	42·43
50–75	14·0	3·20	1·10	8·67	0·38	50·14	42·01
75–100	9·8	2·24	1·10	9·40	0·38	45·75	39·80
100–155	13·1	2·80	0·16	4·93	0·28	40·72	36·96
155–175	12·7	2·80	2·16	6·67	0·18	37·61	35·07
175–185	11·8	3·12	2·33	4·82	0·21	32·65	31·84

Meja Profile

There is a gradual decline in *p*H values with depth in this profile. E.C. values do not exceed 4·0 mmhos/cm. The cations in water-soluble salt in the decreasing order are $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. Except in the surface layer, HCO_3^- is present in higher amounts than CO_3^{2-}. Na^+ and Ca^{2+} decrease with depth but Mg^{2+} does not show such a variation. Cl^- is always higher than SO_4^{2-}. Na^+ is the main exchangeable cation. C.E.C. is the highest in the third layer. S.A.R. and E.S.P. are higher in the upper horizons (Table VI).

TABLE VI

Analysis of the soil extract (1 : 5, soil : water)

Horizons (cm)	*p*H	$CaCO_3$ (%)	E.C. $\times 10^3$	Cations (%)				Anions (%)			
				Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
0–10	10·4	17·4	3·2	0·040	0·012	0·061	0·010	0·078	0·071	0·028	0·005
10–40	9·1	16·1	4·2	0·034	0·013	0·055	0·006	0·086	0·114	0·035	0·012
40–50	9·2	21·2	4·0	0·032	0·010	0·040	0·007	0·072	0·140	0·044	0·011
50–75	9·1	22·1	3·8	0·034	0·013	0·048	0·008	0·080	0·130	0·047	0·008
75–90	8·9	21·2	3·9	0·030	0·014	0·040	—	0·100	0·140	0·040	0·001

Exchangeable cations

Horizons (cm)	C.E.C. (m.e./100 g)	Exchangeable cations, m.e./100 g				S.A.R.	E.S.P.
		Ca^{2+}	Mg^{2+}	Na^+	K^+		
0–10	12·7	1·72	1·02	6·16	0·53	50·00	41·94
10–40	13·8	1·30	0·80	6·25	0·61	40·12	36·58
40–50	14·5	1·40	1·01	7·67	0·17	41·96	36·88
50–75	9·8	1·00	0·91	5·52	0·08	37·64	37·60
75–90	9·4	0·80	0·71	6·45	0·06	43·85	38·72

Chial Profile

It is observed from Table VII that surface soils are associated with higher *p*H values than the sub-soils. The alkaline earth carbonates have decreased in the second layer. E.C. values do not exceed 4·0 mmhos/cm. The surface layer shows the highest amount of soluble Na^+, i.e. 0·092 per cent. Mg^{2+} occupies an intermediate position between Ca^{2+} and K^+. The surface layer appears highly saturated with Na^+. Ca^{2+}, Mg^{2+} and K^+ do not constitute a major fraction of exchangeable cations. C.E.C. is low throughout the profile. S.A.R. and E.S.P. both are high in the upper layers.

TABLE VII

Analysis of the soil extract (1 : 5, soil : water)

Horizons (cm)	pH	$CaCO_3$ (%)	E.C. $\times 10^3$	Cations (%)				Anions (%)			
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
0–10	10·0	12·1	2·5	0·036	0·014	0·092	0·003	0·160	0·185	0·014	0·052
10–50	9·9	11·2	3·8	0·026	0·016	0·054	0·007	0·140	0·120	0·015	0·043
50–65	8·9	12·5	3·9	0·042	0·010	0·044	0·005	0·166	0·110	0·024	0·068
65–90	9·2	14·2	2·8	0·046	0·014	0·060	0·004	0·140	0·085	0·008	0·044
90–140	9·4	15·5	4·1	0·036	0·034	0·048	0·003	0·150	0·062	0·007	0·018

Exchangeable cations

Horizons (cm)	C.E.C. (m.e./100 g)	Exchangeable cations, m.e./100 g				S.A.R.	E.S.P.
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		
0–10	11·4	2·10	1·10	7·12	0·56	58·90	46·04
10–50	9·4	2·40	0·84	6·52	0·46	53·11	43·44
50–65	9·4	3·10	0·68	5·12	0·32	40·06	36·48
65–90	10·5	3·20	1·00	6·12	0·16	32·00	32·33
90–140	8·8	2·10	0·92	4·55	0·10	29·36	29·53

INVESTIGATING THE NATURE OF PROFILES

On the basis of the results obtained, it becomes easy to classify the profiles. A close study of the results reveal that there is a great variation in these profiles with regard to their E.C., $CaCO_3$ (%) and E.S.P. U.S. Salinity workers (1954) have classified alkali soils on the basis of E.C. and E.S.P. In India, Agarwal and Yadav (1956) have classified the soils of Indo-Gangetic alluvium on the lines recommended by U.S. Salinity workers. The alkali soils in the present studies have been classified on similar lines. On the basis of E.C. and E.S.P. the profiles are grouped as:

(1) Saline profile—Ghurpur profile;
(2) Saline-alkali profiles—Handia, Katoghan and Soraon profiles;
(3) Non-saline-alkali profiles—Phulpur, Meja and Chial profiles.

Ghurpur profile is characterized as saline profile because E.C. values are greater than 4·0 mmhos/cm and E.S.P. less than 15·0. These values in the case of Handia, Katoghan and Soraon profiles are more than 4·0 mmhos/cm and 15·0 respectively. In Phulpur, Meja and Chial profiles, E.C. is less than 4·0 mmhos/cm but E.S.P. is greater than 15·0.

Besides E.C. and E.S.P., the profiles exhibit a wide variation in their Cl^{-} and SO_4^{2-} contents. According to Cl^{-}/SO_4 contents, the profiles have been further classified (Plyusnin 1962) (Table VIII).

TABLE VIII

Classification according to Cl^- contents of the profiles

SO_4-type	Cl-SO_4-type	SO_4-Cl-type	Cl-type
Chial (0·48) Katoghan (0·12)	Soraon (0·94)	Phulpur (2·04) Handia (2·04) Ghurpur (1·38)	Meja (7·09)

The above classification finds use in predicting the suitability of the soil in relation to plant growth. For example, presence of 0·3–0·5 per cent contents of Cl^- and SO_4^{2-} hampers the normal growth of crops. According to the concentration and composition of salts, the profiles are further differentiated into the following groups (Plyusnin 1962) as shown in Table IX.

TABLE IX

Classification of soil profiles according to their salinity

Profile	Degree of salinization	Contents of salt in 1 metre layer % with predominance of		
		Chloride		Sulphate
		T.S.S.*	Chloride	Sulphate
Phulpur	Weakly saline	0·22	0·032	—
Handia	,, ,,	0·36	0·028	—
Meja	,, ,,	0·36	0·048	—
Chial	Medium ,,	0·86	—	0·044
Katoghan	,, ,,	0·60	—	0·044
Soraon	,, ,,	0·30	—	0·050
Ghurpur	Strongly ,,	0·60	—	0·16

* Total soluble salts

According to the above classification, the profiles are found to be at different stages of salinization. Phulpur, Handia and Meja profiles are found to contain low amounts of soluble salts, whilst Katoghan, Soraon and Chial contain high amounts of soluble salts.

Not only the salt concentration, but also the presence of individual ions are significant in characterizing the soils. According to cation ratios, as suggested by Ivanova and Rozanov (1939), the profiles have been further classified with respect to different cation ratios (Table X).

According to this classification (Table X), it is found that sodium constitutes one of the major fractions of all the profiles except Ghurpur profile which is classified as Ca-solonchak type.

Both in alkali and saline-alkali profiles, appreciable quantities of $CaCO_3$ is present throughout the profile. $CaCO_3$ in alkali profiles varies from 8·37 to

TABLE X

Classification of profiles according to cationic composition

Profiles	Na+K/Ca+Mg	Ca/Mg	Types
Phulpur ..	2·6	2·8	Sodium-solonchak
Meja	2·4	1·6	,,
Chial	2·4	1·9	,,
Handia ..	2·0	3·0	,,
Katoghan ..	2·3	2·3	,,
Soraon ..	2·1	4·2	,,
Ghurpur ..	0·14	2·8	Ca-solonchak

22·10 per cent, whereas in saline-alkali profiles, it varies from 12·01 to 24·20 per cent. In the saline type, this quantity is not much as it varies between 1·37 and 2·25 per cent. In the first two types, there is a definite accumulation of $CaCO_3$. Agarwal and Mukherjee (1946) also found $CaCO_3$ zone in the alkali soils of Unnao district. CO_3^{2-} and HCO_3^- are the main anions in these two types but in saline soil Cl^- and SO_4^{2-} are the main anions.

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