Chemical changes in original and reclaimed sodic soils of NW India in recent years

G. P. Bhargava

Central Soil Salinity Research Institute, Karnal 132 001, India

Abstract

One reclaimed (Haplustalf) and another unreclaimed (Natrustalf) sodic soil of CSSRI farm at Karnal, Haryana, were studied after a gap of twenty seven years, to evaluate the pedogenic changes that have undergone. The reclaimed sodic soil cultivated to rice - wheat crops showed remarkable improvement in soil properties upto 1.7 m depth. Soluble salts both at surface and sub-surface almost disappeared. Hue of the soil changed from 2.5 Y to 10 YR and value and chroma got decreased. maximum being in the upper 0.8 m depth. Platy and fluffy structure of epipedon transformed into granular, and in the sub-soil, angular blocky structure breaks to granular indicating an overall improvement in soil physical properties. Natrustalf became non-sodic and changed to Typic Haplustalf. Dissolution of native lime has played the key role in bringing about this improvement in the lower horizons. The unreclaimed Natrustalf recorded maximum change in the surface horizon from where the salt efflorescence disappeared due to leaching, as facilitated by periodic ploughing and rain water impounding. Colour of the soil matrix in the major part of the pedon remained unaltered, only slight decrease in chroma in the epipedon was recorded. Structure in the epipedon changed from single grain and fluffy to subangular blocky. Mottles in the sub-surface horizons were not noticed with lowering of the water table. Soil pH and ESP decreased drastically from 10.6 to 8.4 and 96 to 6, respectively. Although there was some lowering of soil pH from 10.2 to 9.5 and ESP from 91 to 61.5 in next horizon, the soil below the surface horizon exhibited alkali nature. Higher values of pH, ESP and the presence of soluble carbonates and bicarbonates with higher electrical conductance confirmed the leaching of highly alkali soil solution. Below the epipedon, the soil presented a typical sodic soil which could be characterised as Natrustalf. Improvement in the epipedon as well as in the upper 0.7 m depth resulted due to dissolution of native lime. Normal ground water indicated similar degree of mineralization and lacked sulphates. This removes the apprehensions regarding the adverse impact of extensive sodic soil reclamation on ground water quality.

Additional keywords : Morphometric changes, pedogenic changes, Haplustalf, Natrustalf, native lime dissolution, Indo-Gangetic alluvial plain

Introduction

Alkali soils of the Indo - Gangetic alluvial plains (IGP) in parts of Haryana and Uttar Pradesh are characterised as Typic Natrustalfs and were established as benchmark soil "Zarifa Viran" (Murthy *et al.* 1982). Before the Central Soil Salinity Research Institute was established in 1969, these alkali soils lay barren for more than a century. After 1969 their amelioration was attempted mainly by application of gypsum. Based on their characteristics, these alkali soils of IGP have been defined as sodic by Bhargava *et al.* (1976) and the genesis has been elucidated by Bhargava *et al.* (1981). Typical sodic soils have extremely deteriorated surface horizon with maximum salt accumulation and the highest degree of sodium saturation therein. Recording the changes in sodic soils after their reclamation may help to evolve reclamation strategies for better land-use planning. The present investigation presents the data acquired in 1997 on chemical changes that have occurred in original sodic soil of the research farm of CSSRI over the last 27 years and also in sodic soil that were reclaimed in 1970.

Materials and methods

Two soil profiles (Pedons 1 and 7) of the farm of CSSRI Karnal (Bhumbla *et al.* 1973) were selected for the present study. Site of pedon 1 was reclaimed through application of agricultural grade gypsum at the optimum rate of 15 t/ha in the surface horizon and rice - wheat rotation was largely followed with dhaincha (*Sesbania aculeata*) as intervening crop in some years. Reclamation was done during *kharif* season of 1970. A profile was examined in summer of 1997 in such reclaimed soil. Original sodic soil was studied near to the site of pedon 7. Horizon-wise soil samples were collected from both the pedons, processed and analysed for their physical and chemical characteristics (Richards 1954). Morphology was described according to Soil Survey Manual (USDA 1951). Calcium carbonate was determined using a Collin's calcimeter (Wright 1939). The field pertaining to pedon 7 (Bhumbla *et al.* 1973) was bunded since 1970 and periodically tilled so as to keep it free from weeds and wild grasses. Soil classification was done as per Soil Taxonomy (USDA 1994).

Results and discussion

Morphometric characteristics of original Natrustalf and the changes occurred in it after reclamation are presented in tables 1 and 2. The original soil exhibited highest pH, maximum accumulation of salts and the highest ESP in the epipedon and these decreased with depth. After 27 years period, the reclamation brought the changes in the 1.7 m. depth. Salt efflorescence disappeared from the soil surface and mottles were no more noticed in the sub-soil of pedon. Soil matrix colour and soil structure exhibited remarkable change. Natrustalfs with hues of 5 Y and 2.5 Y changed to a hue of 10 YR after reclamation. Natrustalfs had values and chromas as high as 6 in some horizons and the reclaimed soil showed lower values and chromas, minimum being in the upper 0.8 m soil depth. Soil structure in the epipedon transformed from weak coarse platy and fluffy to fine granular. The sub- angular blocky structure changed to angular blocky and massive transformed into medium weak granular. The poorly permeable soil transformed into well aerated and well drained one. This is confirmed from conspicuous absence of mottles. The water table which has receded from around 1m depth to about 14 m below the surface has also contributed to improved sub-surface drainage. Absence of salt efflorescence can be ascribed to their neutralisation on gypsum application and subsequent leaching and transformation.

Table 1. Morphometric characteristics of original and reclaimed sodic soils (Natrustalfs)

Horizon	Depth (cm)	Colour (moist)	Mottles colour	Texture	Structure	Consistence
Pedon 1 : Original unreclaimed Natrustalfs (Bhumbla et al. 1973)						
Anz1	0–12	2.5Y 4.5/4	–	sl	c1 platy	fr s p
Anz2	12–34	2.5Y 6/4	2.5Y 6/8	scl	m1 sbk	h s p
Btnz1	34–61	2.5Y 5/4	2.5Y 6/8	l	m2 sbk	vh vs p
Btnz2	61–93	2.5Y 5/4, 5/6	2.5 Y 6/8	cl	c3 abk	vh vs p
Bnz	93–114	2.5Y 4/4	2.5Y 6/8	scl	m1sbk	vh s p
Bk	114–193	2.5Y 4/4, 5/4	–	sl	m	s p
Natrustalfs : 27 years after initiation of reclamation						
Ap	0–20	10 YR 3/3	–	sl	f gr	fr ss p
Bt1	20–40	10 YR4/4	–	scl	m2 abk	vh s p
Bt2	40–80	10 YR3/3	–	l	m3 abk	vh vs p
Bt3	80–106	10 YR5/4	–	cl	m2 abk	vh vs p
B	106–136	10 YR 5/4	–	sl	m1 gr	sh ss p
Bk	136–154	10 YR 5/4	–	sl	m1gr	sh ss p
C	154–170	10 YR 5/4	–	sl	m1 gr	sh so po

Soil pH up to 1 m depth decreased to around 8 and thereafter increased to 8.4 with depth. The ECe values of the pedon were less than 1 dSm^{-1}. ESP recorded reduction but the reduction was remarkable up to 1.06 m depth where it was less than 10 but thereafter it was above 10, maximum being 15.2 at 1.7 m depth. Soluble carbonates were absent and bicarbonate concentration was very low as compared to unreclaimed soil. Sulphate concentration remained between 3.6 and 1.2 me/*l*, which decreased with depth. In bringing about this in improvement, dissolution of native calcium carbonate has played a crucial role.

Table 2. Physical and chemical characteristics of soils under reclaimed condition

Depth (cm)	pHs	ECe dSm^{-1}	CaCO3 <2mm (%)	Ionic composition (me/l) Na^+	Ca^{++} + Mg^{++}	K^+	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	ESP
Original Soil : Pedon 1 (Bhumbla *et al.* 1973)											
0-12	9.0	102.3	2.8	1084.3	1.2	3.6	560.0	236.0	273.6	19.6	95.5
12–34	9.7	6.0	7.8	60.0	1.4	0.3	22.4	22.0	4.0	12.2	92.0
34–61	9.4	2.6	4.4	23.5	3.0	0.3	4.8	14.4	3.6	14.2	86.8
61–93	8.8	1.4	3.4	12.8	0.6	0.1	2.4	9.6	1.6	1.6	85.8
93–114	8.6	0.9	5.9	10.9	0.5	0.2	2.4	7.2	2.4	0.2	75.2
114–192	8.6	0.9	8.4	9.1	0.5	0.1	2.1	3.5	4.0	0.2	24.3
Soil : 27 years after initiation of reclamation											
0–20	8.1	0.94	1.1	2.8	6.5	0.2		3.0	2.9	3.6	6.0
20–40	8.1	0.82	4.2	1.9	6.2	0.1	–	3.0	1.6	3.6	5.6
40–80	8.0	0.57	2.5	1.3	4.5	0.1	–	3.5	0.8	1.6	5.6
80–106	8.1	0.60	2.5	1.5	4.3	0.1	–	3.8	1.4	1.6	7.5
136–154	8.3	0.83	6.5	3.3	5.0	0.1	–	4.0	3.2	1.2	10.6
154–170	8.4	0.75	10.5	2.9	4.5	0.1	–	3.5	2.5	1.5	15.2

With the process of sodic soil reclamation through the application of gypsum at the rate of 15 t/ha in the 15 cm thick surface soil, alkali salts were neutralised, exchangeable sodium was replaced from the exchange sites and soil pH began to fall. With rice-wheat cropping adopted with intervening green manure crops of dhaincha (*Sesbania aculeata*) and periodic applications of FYM, the biotic activity intensified in the soil. The respiration by plant roots and soil flora and fauna coupled with decay of plant residues contributed to CO_2 generation which also influenced the pH. The reduction of pH is therefore approximately proportional to the logarithm of the partial pressure of CO_2 (Russell 1961). Because close relationship has been observed between pH and ESP in alkali soils of the Indo-Gangetic alluvial plain (Bhargava and Abrol 1978), the resultant pH change is bound to influence the ESP. The effective pH in the vicinity of plant roots may be considerably lower than the pH determined in the saturated soil paste because of the greater concentration of CO_2, the roots can maintain in their immediate neighbourhood (Russell 1961). Plant roots therefore contribute more in dissolving native calcium carbonate. The changed morphology, and physical and chemical characteristics justify classification of reclaimed alkali soil as Haplustalf.

Table 3. Morphometric characteristics of Typic Natrustalfs under unreclaimed condition.

Horizon	Depth (cm)	Colour (Moist)	Mottles colour	Texture	Structure	Consistence
Pedon 7 : Unreclaimed Natrustalfs (Bhumbla *et al.* 1973)						
Anz1	0–10	2.5Y 6/4	–	sl	sg	*l* fr ss p
Btnz1	10–48	10 YR 4/4	–	sl	m2 abk	vh fr vs vp
Btnz2	48–76	10 YR 4/3	10 YR 5/6	1	m1 abk	vh fr vs vp
Btnz3	76–104	10 YR5/4	10 YR 5/8	scl	m2 abk	vh fr vs vp
Cnk	104–163	2.5 Y 4.5/5	–	sl	m	h fi vs vp
Unreclaimed Natrustalfs after 27 years (bunded and periodically tilled)						
Ap	0–20	2.5 Y 6/2	–	sl	m1 abk	1 fr vs sp
Btn1	20–45	10 YR4/4	–	sl	m2 abk	vh fi vs vp
Btnz2	45–70	10 YR 4/3	–	1	m3 abk	vh fi vs vp
Btnz3	70–124	10 YR4/4	–	scl	m3 abk	vh fi vs vp
Bk	124–148	10 YR 6/4	–	sl	m	vh fi vs vp
Ck	148–200	10 YR5/4	–	sl	m	h fi s p

Morphometric characteristics of unreclaimed Natrustalf both at the time of acquisition in 1969 and in 1997 are presented in table 3. No amendment was applied but the field was bunded to facilitate rain water conservation. The field was periodically cultivated so as to keep it free from wild grass and weeds. This facilitated leaching and neutralization of a greater part of sodium carbonates and bicarbonates present in the soil and brought about drastic improvement in the upper 20 cm thick soil where the pH decreased from 10.6 to 8.4, ECe from 22.3 to 1.2 dSm^{-1} and ESP from 96 to 6. Soluble carbonates disappeared altogether from this horizon but bicarbonates remained in noticeable amount. Increase in soil pH up to 1.24 m depth indicates maximum impact of leaching sodium carbonate over this part of the pedon. Although EC values registered decrease but compared to surface horizon, the sub-surface horizons indicate increasing trend, likewise the ESP. All other horizons with higher pH values and having presence of soluble carbonates have high ESP. The, marginal reduction in ESP up to 0.7 m depth indicates some leaching of soluble calcium in these horizons under favourable environment. Rain water storage and tillage to bury the weeds facilitated calcium carbonate dissolution. Having turned non-sodic, this horizon might contribute more soluble calcium in future. Change of structure in the epipedon from single grain to medium weak subangular blocky and disappearance of mottles from pedon substratum are the main morphological changes. Matrix colours more or less remained unaltered. Increase in calcium carbonate content may in part be due to illuviation and in part to spatial variability. The unreclaimed soil presented strongly alkali nature from below 20 cm depth which is typical of Natrustalf (Table 4).

Table 4. Changes in physical and chemical characteristics of Typic Natrutalf under unreclaimed conditions.

Depth (cm)	pHs	ECe dSm^{-1}	$CaCO_3$ <2mm (%)	Ionic composition							
				Na^+	Ca^{++} + Mg^{++}	K^+	CO_3^{--}	HCO_3^{--}	Cl^-	SO_4^{--}	ESP
Unreclaimed sodic soil initial characteristics in 1970											
0–10	10.6	22.3	5.1	248.3	0.9	0.4	141.6	136.2	6.6	3.9	96.0
10–48	10.2	6.3	8.9	81.9	1.2	0.1	56.4	20.4	2.8	1.7	91.0
48–76	9.8	4.2	9.4	49.1	0.9	0.1	26.8	19.6	0.8	1.1	88.2
76–104	9.5	2.3	12.6	25.3	1.5	0.1	5.6	17.4	1.4	0.6	85.0
104–163	9.6	1.3	13.8	12.3	1.5	0.1	3.8	7.8	0.3	0.5	69.2
Unreclaimed sodic soil : After twenty seven years											
0–20	8.4	1.2	4.4	6.1	6.0	0.6	–	10.5	1.7	0.5	6.0
20–45	9.5	1.6	8.2	14.4	0.5	0.9	2.5	11.5	1.3	0.5	61.5
45–70	10.0	2.1	8.8	20.0	0.4	0.4	2.5	17.5	0.9	–	83.5
70–124	10.1	2.7	13.5	26.1	0.5	0.4	2.0	23.0	2.0	–	90.4
124–148	8.6	1.2	15.5	9.7	2.5	0.3	–	9.0	3.5	–	16.4
148–200	8.9	2.5	20.8	22.4	2.0	0.4	2.0	18.7	4.1	–	32.5

Absence of specific zones of accumulation of reclamation products like sodium sulphate and very low concentration of soluble sulphate indicates that these have been consumed by various pedogenic processes operating within the soil. It is often opined that applied gypsum shall produce an equivalent quantity of sodium sulphate which shall reach the ground water. Results of ground water quality (Table 5) rule out the possibility of leaching sodium sulphate to deeper strata. Evaluation of water quality over 25 year indicates no noticeable changes in pH and electrical conductance. Both carbonate and sulphate ions remain absent in the ground water which has RSC values of 0.4 me/*l*.

Table 5 : Tubewell water quality at CSSRI farm, Karnal.

Particulars	Year of analysis	pH	EC dSm^{-1}	Ionic composition (me/l)							
				CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Ca^{++} Mg^{++}	Na^+	K^+	RSC
Tubewell No. 1 Block 'A'	1973	8.0	0.40	0.3	2.5	1.3	–	3.3	0.5	–	–
Tubewell No. 2 Block 'B'	1997	8.0	0.45	–	4.0	0.6	–	3.6	1.0	0.03	0.4
Deep tubewell for campus and laboratory block water supply Block 'A'	1997	8.0	0.44	–	4.1	0.6	–	3.6	1.0	0.03	0.4

It may be concluded that amelioration of sodic soils of the Indo-Gangetic alluvial plain through surface application of gypsum, initially improves the surface soil and gradually improves about 1.7 m thick soil profile. Sodium carbonate and exchangeable sodium are neutralized or displaced by soluble calcium in gypsum amended soil. ESP decreased up to 1.7 m depth in amended soil. In unreclaimed soil only surface horizon got improved due to increased biotic activity, tillage, better rain water management, non convergence of surface run-off from adjacent areas and decay of wild grasses and weeds. Sodium carbonate partially leached and a part gets neutralized with dissolution of native calcium but with high ESP. This indicates that the process of reclamation is set in, in this protected environment of the soil but the pace of reactions remains very slow. Therefore, for quicker results it is worthwhile to use an amendment.

The process of reclamation through gypsum application does not deteriorate ground water quality although it is judiciously used for irrigation in the rice-wheat cropping sequence. But the vast expanse of barren alkali soils can be bunded for better rain water storage and to prevent convergence of run-off from neighbouring areas thus facilitating improvement in soil quality. In case of resource crunch this is the only way to bring about improvement in these degraded lands, simultaneously introducing alkali tolerant rice cultivars.

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