Agropedology 2016, 26 (02), 230-236

Characterization and Formation of Salt affected Soils in Bhilwara district, Rajasthan

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Abstract : Soils of the Bhilwara district are affected by different degree and level of soluble salts. These soils had dominant cations *viz*. sodium followed by calcium, magnesium and potassium Exchangeable sodium percentage ranged from 23.1 to 54.6, 17 to 38.5 and 7.1 to 20.0 in saline, sodic and saline-sodic soils, respectively. The Sodium Adsorption Ratio varied from 2.5 to 16.8, 3.2 to 9.4 and 3.8 to 12.6 in these problematic soils, respectively. These soils had pH ranging from 7.6 to 8.4, 8.5 to 9.3 and 8.5 to 8.8 whereas electrical conductivity of saturation extract varied from 14.4 to 25.2, 1.0 to 5.6 and 2.4 to 13.6 dSm^{-1} in saline, sodic and saline-sodic soils, respectively. The saline and saline-sodic soils were moderately well to well drained whereas sodic soils were imperfectly drained. Accumulation of calcium carbonate showed increasing with depth in these soils. Mean values of adjusted sodium adsorption ratio of irrigation water were 43.55, 41.88 and 36.74 for saline, saline-sodic and sodic soils respectively. Use of poor quality underground water for irrigation, aggravated the process of formation of the salt affected soils in eastern Rajasthan Uplands.

Keywords*:* Salt affected soils, saline soil, sodic soil, saline/sodic ground water

Introduction

Accumulation of excess salts in the root zone resulting in a partial or complete loss of soil productivity. Mandal *et al*. (2010) estimated 6.7 Mha area of salt affected soils in India whereas in Rajasthan it occupies in 0.37 million hectare (ICAR 2010) Singh *et al.* (2006) reported 28579 ha (2.73% TGA of Bhilwara) under Sodic Haplusterts. These soils are mainly occurring in Atoli series covering upland areas of Eastern Rajasthan. These soils have been developed due to secondary salinization similar to IGNP canal command area of Rajasthan (Mandal and Sharma 2010). Mathur *et al.* (1968), Kalra and Joshi (1996) and Mandal and Sharma (1997) have characterized the salt affected soils of Rajasthan using remote sensing imageries and soil studies. However, studies on the pedogenic nature of salt affected soils and characterization is required for deciding the reclamation and management options and proper land use planning and hence present study was carried out in Bhilwara district of Rajasthan.

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Materials and Methods

Study area is part of eastern Rajasthan upland (25° 01' to 25° 58' N ; 74° 01' to 75°28' E) at an elevation between 380 and 500 above msl. Bhilwara district has three physiographic units *viz*., Eastern plain, Aravalli and Vindhyan landscape. The climate is characterized by hot and dry summer and a cold winter season. The average rainfall of the region is 699 mm, most of which is received during the monsoon months from mid June to mid September. The area is characterized by semi-arid hot dry semi-arid Agro Ecological Sub Region.

White salt patches were identified based on the interpretation of IRS FCC at 1:50,000 scale (Mandal *et.al*. 2010). Six representative pedons were studied morphometrically (Soil Survey Division Staff, 1995). The horizon-wise soil samples were collected, dried, processed by 2.0 mm sieve for analysis of physico-chemical properties. Water samples were collected from the tube wells and open dug wells for chemical analysis.

The particle size and bulk density were determined by standard method (Black 1965). Soil pH, electrical conductivity of saturation paste, organic carbon were determined by the methods described by Jackson, (1973). The free calcium carbonate was determined by the procedure outlined by Piper, (1950). The saturated extract was analyzed for Ca^{++}, Mg^{++}, Na^{+}, K^{+}, bicarbonate and chloride and sodium adsorption ratio and exchangeable sodium percentage were determined by the methods outlined by Richards, (1954). The neutral ammonium acetate method was used to determine exchangeable bases and cation exchange capacity as per Richards (1954). The adjusted SAR of water was computed (Ayers and Westcot 1976).

Results and Discussion

The soil site and morphological characteristics of salt affected hills are given in table 1.

Table 1. Soil-site and morphological characteristics of salt affected soils

Site characteristics	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
Location	Ratanpur	Mataji ka Kheda	Mushi	Samelia	Sareri	Pander
Longitudes	$74^{0}21^{'}12^{''}$N	$74^{0}44^{'}28^{''}$ N	$74^{0}46^{'}28^{''}$ N	$74^{0}48^{'}60^{''}$ N	$74^{0}26^{'}00^{''}$N	$75^{0}16^{'}21^{''}$N
Latitudes	$25^{0}33^{'}17^{''}$E	$25^{0}23^{'}34^{''}$ E	$25^{0}35^{'}58^{''}$ E	$25^{0}39^{'}25^{''}$ E	$25^{0}38^{'}07^{''}$E	$25^{0}38^{'}16^{''}$E
Geomorphic unit	Plain	Plain	Plain	Plain	Plain	Plain
Mean annual rainfall (mm)	600-700	600-700	600-800	600-800	600-800	600-800
Textural variation	cl	sc - c	sl - ls	sc - c	sl - scl	scl - sc
Depth to kankar layer	42 cm	51 cm	24 cm	53 cm	31 cm	45 cm
Mottles	-	present	present	present	-	-
Parent material	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium
Drainage	Well	Mod. well	Imp.to mod. well	Mod.well	Well	well
Land use	Barren	Sparse vegetation	Single crop	Pasture	Barren	Single crop

Physico-chemical characteristics

The saturation extract of saline soils had an electrical conductivity >4 dSm^{-1}, exchangeable sodium percentage <15 and pH < 8.5. Saline-sodic (alkali) soils had ECe >4 dSm^{-1}, ESP >15 and pH is seldom above 8.5and accordingly soils of Bhilwara were placed in saline, sodic and saline-sodic groups.

Sand, silt and clay content ranged from 21.2 to 51.7, 8.2 to 38.3 and 31.1 to 62.7%, respectively in saline soils and, in general clay increases with depth (Table 2). Bulk density ranged from1.2 to 1.5Mg m^{-3}. The pH varied from 7.6 to 8.4 while ECe varied from 14.4 to 25.2 dSm^{-1}. However, an extreme low ECe (1.3 dSm^{-1}) was recorded at the depth of 65-90cm in soils of Ratanpur (P1). Organic carbon content ranged from 4.0 to 7.7gkg^{-1} and it decreased with depth in soils of Ratanpur and Mataji Ka Kheda. Calcium carbonate ranged from 57.0 to 293.2gkg^{-1} and in general, increased with depth. Cation exchange capacity (CEC) was found to vary from 20.9 to 43.9 cmol(p^{+}) kg^{-1} (table 2). Sand, silt and clay content ranged from 21.2 to 51.7, 8.2 to 38.3 and 31.1 to 62.7%, respectively in saline soils (Table 2). In both the profiles of saline soils, clay migration was observed from surface to subsurface layers. Bulk density ranged from1.2 to 1.5Mg m^{-3}. The pH varied from 7.6 to 8.4 while ECe varied from 14.4 to 25.2 dSm^{-1} in general. However, an extreme low

ECe (1.3 dSm^{-1}) was recorded at the depth of 65-90cm in soils of Ratanpur (P1). It might be due to the presence impermeable layer formed with combined impact of clay (38.9%) and powdered calcium carbonate (192.1 g kg^{-1}). Organic carbon content ranged from 4.0 to 7.7gkg^{-1} and it was recorded decreasing down the depth in soils of Ratanpur and Mataji Ka Kheda. Calcium carbonate was ranged from 57.0 to 293.2gkg^{-1}. In general, accumulation of calcium carbonate showed increasing trend with depth of profile with an exception of 15-33cm depth of Mataji Ka Kheda (P2). Cation exchange capacity (CEC) was found to vary from 20.9 to 43.9 cmol(p^+)kg^{-1}.

Table 2. Physico-chemical characteristics of salt affected soils

Pedon	Horizon	Depth cm	Sand	Silt	Clay	B.D. Mgm^{-3}	pH	Ece dSm^{-1}	OC	CaCo3
			---------------%-------------						-------gkg^{-1}-----	
Saline Soils										
P1	A1	0-19	30.6	38.3	31.1	1.3	7.6	33.2	7.7	57
	Bw1	19-42	34.1	33.7	32.2	1.3	7.7	32.0	7.5	97
	Bw2	42-65	31.1	33.2	35.7	1.4	8.0	25.2	4.0	152
	Bw3	65-90	25.6	35.5	38.9	1.5	7.6	1.3	4.0	192
P2	A1	0-15	51.7	8.2	40.2	1.2	8.3	20.0	6.4	273
	Bw1	15-33	21.2	17.0	62.8	1.4	8.2	18.2	5.6	142
	Bw2	33-51	22.9	14.4	62.7	1.3	8.4	14.4	4.9	293
Sodic Soils										
P3	Ap	0-24	70.6	11.6	17.8	1.3	8.5	1.0	3.4	223
	2Ck1	24-50	75.0	10.9	14.1	1.4	9.2	3.3	3.3	243
	2Ck2	50-75	82.7	6.6	10.5	1.3	9.3	4.2	3.3	279
P4	Ap	0-15	38.5	31.5	30.0	1.3	8.6	1.4	7.5	79
	2Bw1	15-35	25.7	13.8	60.5	1.4	8.7	3.2	7.2	62
	3Bwk	35-53	48.1	6.9	45.0	1.4	8.7	4.4	5.0	2
	4Ck	53-72	50.2	7.9	42.0	1.4	8.6	5.6	4.1	232
Saline - Sodic Soils										
P5	A1	0-13	64.3	16.7	19.0	1.2	8.5	2.4	4.8	152
	2Ck1	13-31	60.0	20.2	19.7	1.3	8.5	6.4	4.8	173
	2Ck2	31-57	50.2	27.4	22.4	1.3	8.5	13.6	4.1	174
	4Ck3	57-82	68.1	12.7	19.2	1.4	8.8	2.8	3.9	202
P6	Ap	0-18	50.4	26.9	22.7	1.4	8.5	2.9	8.4	30
	2A1	18-33	54.7	24.5	20.8	1.5	7.9	9.6	6.1	40
	2A2	33-45	53.8	24.6	21.7	1.4	8.5	12.3	5.2	63
	3Ck1	45-79	48.6	12.7	38.7	1.5	8.6	12.3	3.4	193
	4Ck2	79-105	50.1	19.7	40.1	1.5	8.6	12.5	3.4	210
	5Ck3	105-140	47.8	11.4	40.8	1.5	8.7	13.0	3.2	249

The sand, silt and clay content ranged from 25.7 to 82.7, 6.6 to 31.5 and 10.5 to 60.5%, respectively in sodic soils (Table 2). Bulk density ranged from 1.3 to 1.4Mg m^{-1}. The pH varied from 8.5 to 9.3 while ECe varied from 1.0 to 5.6dSm^{-1}. Organic carbon content ranged from 3.3 to 7.5g kg^{-1} and decreased with depth in both the pedons. Calcium carbonate ranged from 62 to 279gkg^{-1}. However, a relatively low content of calcium carbonate (2 g kg^{-1}) was observed at depth of 35-53cm in P4. The calcium carbonate increased with depth in P3. Cation exchange capacity (CEC) ranged from 8.3 to 40.5 cmol(p^+)kg^{-1}.

The sand, silt and clay content ranged from 47.8 to 68.1, 11.4 to 26.9 and 19.0 to 40.8%, respectively in saline-sodic soils (Table 2) and clay increased. Bulk density ranged from 1.2 to 1.5Mg m^{-1}. The pH varied from 8.5 to 8.8 except second horizon P6 while ECe varied from 2.4 to 13.6dSm^{-1}. Organic carbon content ranged from 3.2 to 8.4 g kg^{-1} and it decreased with depth in both the pedons. Calcium carbonate ranged from 31 to 249 g kg^{-1} with a tendency to increase with depth. Cation exchange capacity (CEC) varies from 13.6 to 28.4 cmol (p^+)kg^{-1}. The CEC showed higher value in sub-surface horizons.

Water extractable ions

Water extractable calcium, magnesium, sodium and potassium ions ranged from 55 to 175.2, 29 to 140, 10.3 to 176 and 0.3 to 6.0$mEqL^{-1}$, respectively (Table 3). Likewise, anions namely CO_3+HCO_3, Cl and SO_4 ranged from 2 to 7, 22.5 to 137.5, and 20.1 to 333.5$mEqL^{-1}$ respectively. Among the anions the exchange complex were dominated by SO_4 followed by Cl in saline soils.

Table 3. Extractable ions in saturated paste of salt affected soils

Pedon	Depth cm	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}+HCO_3^{-}	Cl^-	$SO4^{--}$	ESP	SAR
		----------mEq/L----------								
					Saline Soils					
P1	0-19	175.2	124.8	176.0	6.0	7.0	127.5	347.5	36.5	14.4
	19-42	160.0	140.0	162.0	6.0	7.0	127.5	333.5	34.6	13.2
	42-65	108.6	71.4	159.0	3.4	6.0	82.5	253.9	46.4	16.8
	65-90	32.0	2.0	10.3	0.3	2.0	22.5	20.1	23.1	2.5
P2	0-15	101.4	96.6	99.8	2.8	5.0	122.5	173.1	33.2	10.0
	15-33	84.6	75.4	102.0	2.2	8.0	137.5	118.7	38.6	11.4
	33-51	55.0	29.0	101.5	0.3	2.0	130.0	53.8	54.6	15.7
					Sodic Soils					
P3	0-24	6.8	2.4	6.8	0.2	2.0	9.0	5.2	17.7	3.2
	24-50	10.0	8.8	22.8	1.0	7.0	12.0	23.6	35.4	7.4
	50-75	10.2	9.4	29.3	1.9	8.0	30.0	12.8	38.5	9.4
P4	0-15	7.8	4.8	8.3	0.8	2.0	13.0	6.7	17.0	3.3
	15-35	10.4	9.6	19.9	1.1	2.0	18.0	21.0	18.3	6.3
	35-53	18.2	9.8	28.0	1.2	3.0	30.0	24.2	22.2	7.5
	53-72	20.2	10.6	27.6	1.4	4.0	32.0	23.8	23.1	7.0
					Saline - Sodic Soils					
P5	0-13	8.2	4.6	17.0	0.6	8.0	12.0	10.4	15.9	6.7
	13-31	25.0	24.0	38.2	0.3	8.0	24.0	55.5	17.2	7.7
	31-57	75.0	50.0	61.3	2.1	9.0	35.0	144.4	20.0	7.8
	57-82	7.4	5.0	21.2	0.3	9.0	12.0	12.9	18.0	8.5
P6	0-18	19.6	4.0	21.6	0.7	3.0	30.0	12.9	17.2	6.3
	18-33	65.6	34.4	43.5	0.8	5.0	45.0	94.3	11.0	6.2
	33-45	100.0	60.0	33.8	2.3	4.0	90.0	102.1	7.1	3.8
	45-79	45.4	38.6	75.5	2.2	8.0	90.0	63.7	18.3	11.6
	79-105	50.0	38.0	78.6	3.7	7.0	82.5	80.8	18.3	11.8
	105-140	60.0	27.4	83.0	2.6	8.0	82.5	82.5	19.2	12.6

Calcium, magnesium, sodium and potassium ranged from 6.8 to 20.2, 2.4 to 10.6, 6.8 to 28.0 and 0.2 to 1.9mEqL^{-1}, respectively (Table 3). Similarly, anions namely CO_3^-+HCO_3^-, Cl^- and SO_4^- ranged from 2.0 to 8.0, 9.0 to 32.0 and 5.2 to 23.8mEqL^{-1} respectively in sodic soils.

Calcium, magnesium, sodium and potassium ranged from 7.4 to 100.0, 4.0 to 60.0, 17.0 to 83.0 and 0.3 to 3.7mEqL^{-1}, respectively (Table 3). Likewise, CO_3+HCO_3, Cl and SO_4 ranged from 3.0 to 9.0, 12.0 to 90.0, and 10.4 to 144.4mEqL^{-1} respectively in saline sodic soils.

Exchangeable Sodium Percentage and Sodium Adsorption Ratio

Exchangeable sodium percentage ranged from 23.1 to 54.6, 17 to 38.5 and 7.1 to 20.0 in saline, sodic and saline-sodic soils, respectively. The SAR varied from 2.5 to 16.8, 3.2 to 9.4 and 3.8 to 12.6 in saline, sodic and saline-sodic soils, respectively (Table 3). High exchangeable sodium in sodic soils had marked influence on the physical soil properties due to dispersion of soil particles. The rise in pH due to high exchangeable sodium interfere in the availability of nutrients.

Irrigation water quality

The pH ranged from 7.83 to 8.13, 7.65 to 8.46 and 7.52 to 8.2 in saline, sodic and saline-sodic soils, respectively (Table 4). The electrical conductivity of irrigation water ranged from 1.10 to 12.50 in saline soils, 1.12 to 6.40 in sodic and 1.28 to 2.56 in sodic-saline soils. Adjusted sodium adsorption ratio of irrigation water samples in saline soils was ranged from 21.93 to 76.29 with a mean of 43.55 whereas in sodic soils it was ranged from 17.71 to 82.49 with a mean of 41.88. The irrigation water of saline sodic area had adj. RNa between 21.33 and 76.85 with a mean of 36.74.

Formation of soil

Saline soils: the saline soils occur in plain area surrounded by some elevated areas. The abundance of the chloride and sodium in saturation extract is due to preferential geochemical weathering of sodium and chloride bearing minerals from granitic and gneissic rocks of Aravali hills (Sarin 1952). High salinity of the ground water (Table 4) has been the main source of soil salinisation in this region. Use of irrigation water with high salinity cause a buildup of salts in the root zone, particularly if the internal drainage of the soils is restricted and leaching, either due to rainfall or applied irrigation, is inadequate. Soluble salts moved from areas of higher to lower elevations, from relatively wet to dry areas, from irrigated fields to adjacent unirrigated fields. Localized redistribution of salts caused salinity problems to a significant magnitude in the region.

Table 4. Quality of irrigation water in the vicinity of salt affected soils

Parameter	pH	EC dSm^{-1}	Adj. SAR	Fluoride Mgkg^{-1}
		Saline soils		
Range	7.83-8.13	1.10-12.50	21.93-76.29	4-5.05
mean		8.38	43.55	4.51
		Sodic soils		
Range	7.65-8.46	1.12-6.40	17.71-82.49	3.80-6.02
Mean		3.9	41.88	4.52
		Saline - Sodic soils		
Range	7.52-8.20	1.28-2.56	21.33-76.85	4-7.90
Mean		2.08	36.74	5.97

Saline-sodic/sodic soils: This type of soils developed due to irrigation with ground waters having moderate salinity (EC 1.12 to 6.40 dSm^{-1}) with high adjusted SAR (17.71 to 82.49). The scanty rainfall with high aridity index and high PET accentuate the process of accumulation of high concentration of soluble salts with high SAR. Mehta *et al*. (1969) have reported that it was a usual practice in Bhilwara to construct water tank with mud boundary above ground surface for storing rain water to irrigate crops. It was observed that presence of calcium carbonate within 50 cm depth of soil restrict the movement of natural ground water. Such conditions in the area raise water table up to a critical depth which does not allow the leaching of soluble salts. Same cycle repeated year after year in such zone leads to development of saline-sodic soils. Groundwater containing high carbonate and bicarbonate is one of the chief contributing factors in the formation of sodic soils in this region. Bhargava *et al.* (1980) reported that alternate wet and dry seasons and the topographic (drainage) conditions appeared to be the contributing factors in the formation of vast areas of sodic soils in the Indo-Gangetic plains of India. During the wet season, water containing weathered alumino-silicates accumulate in the low lying areas. In the dry season, as a result of evaporation, the soil solution is concentrated resulting in the precipitation of the divalent cations, causing an increase in the proportion of sodium ions in the soil solution and on the exchange complex with simultaneous increase in pH. This process repeated over years resulted in the formation of sodic soils.

Conclusion

It is observed that the soils of the area were primarily affected with accumulation of chlorides and carbonates of sodium/calcium. Topographical and morphological features of soil indicated that conversion of normal soils to salt affected soils has been started with initiation of salinization in pockets having impeded drainage conditions. These pockets received rain water flowing from nearby elevated parts of land surface. Under semi-arid environment water gets evaporated and salts are left on soil surface. Such process was more intense in areas where either ground water was used for irrigation or areas using harvested rain water in tanks with mud boundary which facilitates lateral movement of salts in low lying area. This process of secondary salinization continued for several years in this area. With the passage of time, the sodium salts got accumulated. The concentration of Na reached to such a critical level that divalent ions (Ca/Mg) started to precipitate with bi-carbonates/carbonates *i.e*. initiated the process of calcification. This precipitated calcium carbonate has been deposited within a depth of 50 cm and impeded the downward movement of water and other soluble salts (in case of saline-sodic soils). Under impeded drainage conditions, sodium ions have undergone the hydrolysis and form hydroxides of sodium which raise soil pH up to a level of 9.4.

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Received: July 2016 *Accepted: November 2016*