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Role of swelling mineral in fixing lower limit of exchangeable sodium percentage for sodic soils

S.S. Balpande, P.R. Kadu, D.K. Pal, T. Bhattacharyya and S.L. Durge

Division of Soil Resource Studies, National Bureau of Soil Survey & Land Use Planning, Amravati Road, Nagpur 440 010, India.

Abstract

Explanations with regard to the observed loss of soil productivity due to poor drainage condition below and at 15 ESP (exchangeable sodium percentage) of deep black soils (Sodic Haplusterts and Sodic Calciusterts) and also at 50 ESP of alluvial soils (Typic Natrustalfs) in contrast to current universal minimum value of 15 ESP, are lacking at present. As the poor drainage condition is related to dispersion and swelling of clay minerals, two benchmark soils representing two types of soils were analysed for their detailed qualitative and quantitative mineralogy alongwith with their sodicity related physical and chemical properties. Results of this study indicate that the variance in the lower limit of ESP is due to huge amounts of smectite (491 g kg^{-1}) in the former and to very small amount of smectite (46 g kg^{-1}) in the latter soil. The study suggests that the current lower limit of 15 ESP of United States Salinity Laboratory for all the soils is arbitrary and tentative and thus it would be prudent to evaluate the lower limit of ESP in view of loss of productivity in different group of soils.

Additional key words: Black soils, mineralogy, smectite, alluvial soils.

Introduction

Sodic soils generally have poor physical properties due to high exchangeable sodium and pH, resulting in restricted water and air movement (Acharya and Abrol 1978; Varallyay 1978). An exchangeable sodium per cent of 15 has been used at the United States Salinity Laboratory as boundary limit between nonsodic and sodic soils. Compared with the critical limiting ESP value of 15 for deterioration in soil structure a considerably lower ESP value of 6 has been suggested for soils with an abundance of fine clay and lacking in soluble weatherable minerals to maintain electrolyte concentration of soil solution during leaching (Northcote and Skene 1972; Shanmuganathan and Oades 1983). Balpande *et al.* (1996) suggested that ESP 5 should be used as the lower limit for sodic subgroups of Vertisols of central India, rather than ESP 15 as given in *Keys to Soil Taxonomy* (Soil Survey Staff 1994). This is because there are severe limitations to the use of such soils owing to the development of adverse physical conditions in terms of very poor drainage even at such a low ESP. On the other hand Vertisols of Western India with an ESP around 15 have very poor physical condition causing extreme difficulty in tillage operations (Bhattacharyya *et al.* 1994).

The relative performance of various crops in soils of the Indo- Gangetic alluvial plains at different soil sodicity levels has been compiled from some of the experiments conducted at the Central Soil Salinity Research Institute, Karnal, India (Abrol and Fireman 1977). Sodicity tolerance ratings of different crops indicate that 50 per cent reduction in relative rice yields is observed when ESP is above 50 and for wheat it is around 40.

The adverse physical properties of sodic soils are caused primarily by clay dispersion and swelling which cause hydraulic conductivity reductions and blockage of water conducting pores (Frenkel *et al.* 1978; Pupisky and Shainberg 1979; Balpande *et al.* 1996). Recent evidence shows that dispersion of soil colloids is a determinant of a range of soil properties and among them clay mineral type appears to be one of most important factors (Gupta and Abrol 1990). However, such understanding is yet to be gained for sodic soils of the country.

In view of this the present study was undertaken to find out possible role of nature and content of clay mineral type that may support the observed variance at the lower limit of ESP of black and alluvial soils.

Materials and methods

Soils

Fourteen sodic/saline sodic soils, four from the southwestern part of the Purna valley in Akola district of Maharashtra (Sodic Haplusterts, Balpande *et al.* 1996); six from Porbander tehsil, Gujarat (Sodic Calciusterts, Bhattacharyya *et al.* 1994); two from Karnal and Jind districts of Haryana (Typic Natrustalfs, Pal and Bhargava 1985) and another two from Etah and Lucknow districts of Uttar Pradesh (Typic Natrustalfs, Pal *et al.* 1994; Srivastava *et al.* 1994), were selected for the present study.

Sodic black soils (Sodic Haplusterts) of Maharashtra lack any perceptible evidence of salt efflorescence on the soil surface which would indicate the presence of salt, but the drainage conditions are poor. Thus the soils remain waterlogged after rain which considerably disrupts the schedule of sowing crops during the rainy season.

Sodic calcareous black soils (Sodic Calciuserts) of Gujarat show evidence of salt efflorescence which increases down the depth. The ground water of this area is highly sodic and saline. Thus whenever such water has been used for supplemental irrigation, the increase of sodicity in the surface horizons has further impaired drainage and also resulted in the accumulation of salts on the soil surface.

Sodic alluvial soils (Typic Natrustalfs) of Haryana and Uttar Pradesh look barren and do not support any agricultural crops if not reclaimed.

The soil-site characteristics of three representative benchmark soils are given in table 1. However, clay mineralogical investigations were done for two pedons representing one each of Vertisols and alluvial soils.

Analytical methods

Sand (2000-50μm), silt (50-2μm), total clay (<2μm) and fine clay (<0.2μm) fractions were separated from the samples after dispersion according to the size segregation procedure of Jackson (1979). Soil pH and electrical conductivity (ECe) were measured by standard methods (Richard 1954). Cation exchange capacity (CEC) and exchangeable sodium and potassium were determined following the method of Richards (1954), substituting 1N $Mg(NO_3)_2$ of pH 8.6 for NH_4OAc to eliminate the influence of zeolites and feldspathoid minerals (Gupta *et al.* 1985). Exchangeable calcium and magnesium were determined following 1N NaCl solution extraction method of Piper (1966). The saturated hydraulic conductivity (HC) was determined using a permeameter by the constant head method of Richards (1954).

The silt and clay fractions were subjected to X-ray diffraction (XRD) analysis of parallel oriented slide mounts after Ca- and K- saturation (Jackson 1979), using a Philips diffractometer with Ni- filtered Cuk α radiation and a scanning speed of $2^{o}2\theta$/min. Semi-quantitative estimates of the clay minerals were made following the principles outlined by Gjems (1967) and Kapoor (1972).

Results and discussion

General properties of soils

Sodic Black Soil (Sodic Haplustert): The soils are very deep (> 140 cm) and fine textured. The fine clay to total clay ratio generally ranges between 0.4 to 0.6. The CEC of the soils as well as clay are very high. Clay CEC is 90 in the soil control section (SCS) indicating the dominance of smectite mineral in the clay fraction (Table 1).

The soils have ECe less than 4 dS m^{-1}, indicating no salinity hazard. Calcium is dominant exchangeable cation followed by magnesium, sodium and potassium. The ESP values gradually increase with depth with more than 15 in deeper horizons (Table 1), indicating the initiation of sodification in the lower horizons. These soils qualify as Sodic due to pH, ECe and ESP values (Richards 1954), and are Sodic Haplusterts according to Keys to Soil Taxonomy (Soil Survey Staff 1994). The subsurface (Bss) horizons with an ESP of 5 and HC of less than 1.0 mm hr^{-1}, indicate very poor internal drainage condition.

Sodic Calcareous Black Soil (Sodic Calciustert): These soils are moderately deep to deep and are fine. The fine to total clay ratios range between 0.5 to 0.55. The CEC of soils and clay are high as shown in table 1. Clay CEC is 97 in SCS indicating the dominance of smectite mineral of soils.

These soils have ECe more than 4 dS m^{-1} which indicate slight salinity hazards. These soils have higher Mg as exchangeable cation especially in the subsurface horizons. Sodium and potassium are the other exchangeable cations (Table 1). These soils have more than 15 cm thick horizons with carbonate content equivalent to more than 15 per cent $CaCO_3$ and contain appreciable amount of soft powdery lime indicating the presence of calcic horizon. The presence of high (15) ESP indicates that these soils to be grouped into Sodic Calciusterts (Soil Survey Staff 1994). Higher ESP and very low HC indicate poor internal drainage condition of these soils.

Sodic Alluvial Soils (Typic Natrustalf): These soils are moderately deep (100 cm), loamy textured and have clay enriched textural B-horizons. The fine clay to total clay ratio ranges between 0.30 to 0.40, and the CEC between 6 to 16 cmol(p +)kg^{-1}. Although the clay CEC on SCS basis shows higher values (50 cmol(p +)kg^{-1}) possibly due to the presence of small amount of expansible clay minerals, the mineralogy class is mixed in view of low soil CEC. The presence of expansible minerals like smectites is often reported in such soils (Pal *et al.* 1994).

These are typical alkali soils with preponderance of bicarbonate and carbonate of sodium with high pH ranging upto 10.5 and ESP values as high as 80-90 throughout the profile depth. Despite their higher ECe value (4 dS m^{-1}), these soils remain waterlogged after rains because of very poor drainage condition. The HC of these soils is very low (1 $mmhr^{-1}$) caused by high level of ESP due to carbonates and bicarbonates of sodium.

Table 1. Some physical and chemical properties of soils

Location of soils	Parent material	Horizon	Depth (cm)	pH 1:2	ECe dS/m	Sand 2000-50u	Silt 50-2µ	Clay <2µ	Fine clay <0.2µ	Textural class	CEC Soil	CEC Clay	ESP	HC mm/hr	$CaCO_3$ g/Kg
						<------	%		------>		cmol (+)/kg				
						Sodic Haplustert[1]									
South western part of the Purna valley, Maharashtra	Basaltic alluvium	Ap	0-15	8.5	0.5	1.6	26.5	71.9	28.9		61.7	86.0	4.1	2.3	38.0
		A	15-32	8.8	0.6	1.3	26.7	72.9	35.5		63.5	87.0	5.0	1.0	38.0
		Bss1	32-98	8.8	0.4	1.3	30.4	68.3	32.7	Clay	61.7	90.0	11.2	0.4	42.0
		Bss2	98-126	8.7	1.1	3.4	37.1	59.5	26.8		58.3	98.0	15.8	0.3	85.0
											(60)	(90)			
						Sodic Calciustert[2]									
Rinawada, Porbander, Junagarh, Gujarat	Marine alluvium	A	0-12	8.1	1.8	9.2	32.1	58.7	24.0		50.0	85.0	17.2	1.5	13.2
		Bss	12-32	8.3	4.5	13.1	27.6	59.3	27.0		52.0	88.0	25.6	0.4	14.2
		Bssk	32-68	8.2	6.5	13.9	29.4	56.7	27.2	Clay	56.0	99.0	35.0	0.3	26.5
		2Ck1	68-87	8.1	7.3	26.0	25.5	48.5	24.0		45.0	93.0	21.5	0.1	25.5
		2Ck2	87-105	7.8	9.0	49.0	20.1	38.9	15.6		40.0	103.0	25.2	0.1	25.2
											(50)	(97)			
						Typic Natrustalfs[3]									
Zarifa Viran soil, CSSRI, Karnal, Haryana	Indo-Gangetic alluvim	A1	0-6	9.5	75.4	61.2	27.6	12.8	4.5		6.5	50.0	92.0	2.0	15.0
		A2	6-18	10.5	11.7	54.2	27.2	18.2	6.4		12.0	66.0	87.0	1.0	10.0
		B	18-49	10.4	6.2	50.6	23.6	22.2	8.7	Loam	13.5	61.0	88.0	0.8	18.7
		Bt	49-74	10.2	4.5	52.7	28.4	23.7	9.7		16.0	67.0	87.0	0.7	27.1
		2Bk	74-136	9.9	3.0	52.6	15.8	19.0	4.6		12.0	63.0	83.0	0.7	222.5
											(14.0)	(64.0)			

Values in brackets indicate the CECs of soil and clay on control section basis.
Sources : 1. Balpande *et al.* 1996; 2. Bhattacharyya *et al.* 1994; 3. Pal and Bhargava 1985.

Mineralogy of the soils

Sodic Haplustert: The silt fraction (50- 2μm) of the soils contain quartz, plagioclase, K-feldspar, anatase, cristobalite, amphibole, chlorite, mica, kaolinite, smectite, 10-14A^{o} minerals and vermiculite (Fig.1). It is interesting to note the presence of small amount of smectite in these soils. However, this is very common in Vertisols of central and western Peninsular India (Pal and Deshpande 1987).

The total clay (<2μm) is composed of smectite, chlorite, vermiculite, mica, 10-14A^{o} mineral and kaolinite with additional small amounts of quartz and feldspar (Fig.1). This fraction contains considerable amount of smectite (700 g kg^{-1}) (Table 2).

Table 2. Semi-quantitative estimates of the clay minerals

Horizon	Clay minerals in <2μm clay fraction (g kg^{-1})						Smectite on fine earth basis	
	Sm[1]	Vm	ML	M	K	Ch	(g kg^{-1})	SCS
				Sodic Haplustert				
Ap	700	60	60	8	Tr[2]	100	504	
A	710	60	60	70	Tr	100	520	
Bss1	720	50	50	50	50	80	490	491
Bss2	750	50	50	50	Tr	100	446	
BC	730	60	60	60	Tr	100	390	
				Typic Natrustalf				
A1	120	70	220	460	90	60	15	
A2	160	90	210	420	70	50	29	
B	280	20	160	360	60	120	62	46
Bt	330	50	150	340	50	80	78	
2Bk	170	Tr	190	370	160	116	32	

1 Sm = smectite, Vm = vermiculite, ML-mixed layer minerals (10-14A^{0} minerals), M = mica, K = kaolinite, Ch-chlorite;

2 Tr = Trace

In the fine clay fractions smectite is the dominant clay mineral with minor amounts of mica and kaolinite. Smectite makes up more than 95 per cent of the fine clay. On K-saturation at 25^{o}C smectite peak shifts to 11-12A^{o}, a characteristic of low charge smectite which further collapses to 10A^{o} when heated to 550^{o}C (Fig.1).

Typic Natrustalf: The XRD of the silt fraction indicates that besides quartz and feldspar, the 10 and 14A^{o} minerals are distinctly present (Fig.2). In addition, 10-14A^{o} minerals are also present. The 14A^{o} minerals are confirmed to be vermiculite and chlorite. No smectite could be detected.

Qualitatively the mineral composition of the total and fine clay was similar throughout the profile depth (Fig.2). Total clay consists of mica, 10-14A^{o} minerals, vermiculite, smectite, chlorite and kaolinite whereas mica, mixed-layer minerals, vermiculite, smectite and traces of kaolinite are present in the fine clay. The smectite

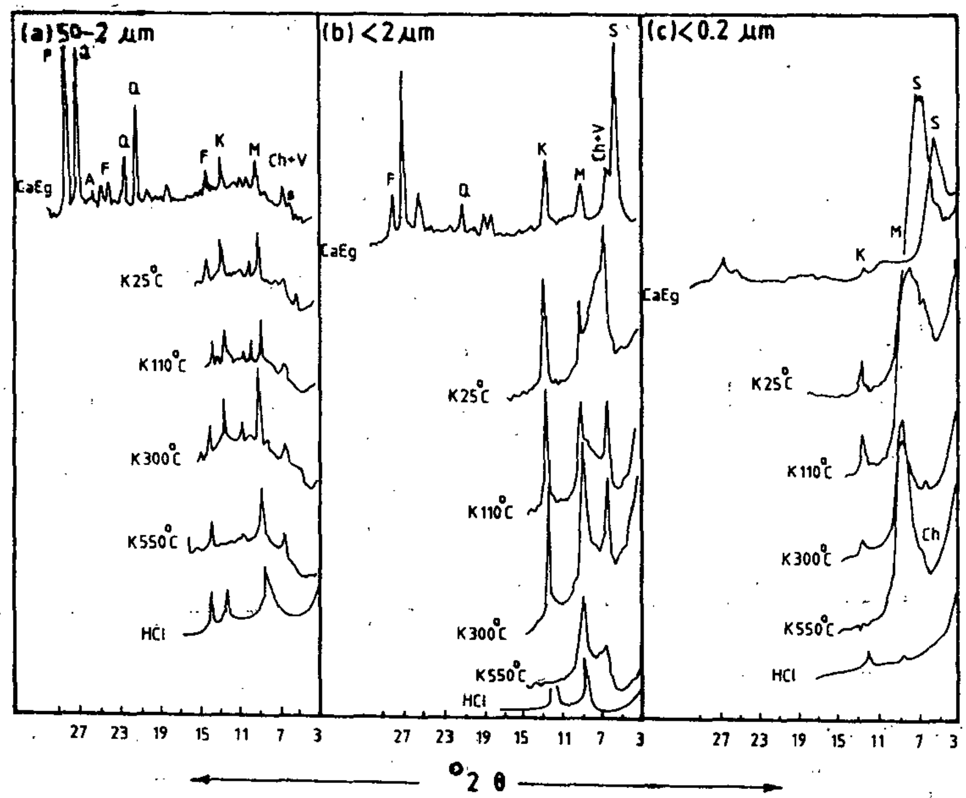

Fig.1.Representative XRD diagrams of silt (a), total clay (b) and fine clay (c) fractions of black soils: CaEg=Ca- saturated and glycolated, K25°/110°/300°/550°= K- saturated and heated, S=smectite, M=mica, V=vermiculite, K=kaolinite, Ch=chlorite, F=feldspars, Q-Quartz, A=anatase.

expands to 17A° on glycolation but readily contracts to 10A° on K-saturation at 110°C indicates its high charge density.

Physical and chemical properties of soils (Table 1) indicate that both Sodic Haplusterts/Calciusterts and Typic Natrustalfs have very low HC. Swelling and dispersion of clay have been proposed as explanations for decrease in soil permeability as a result of monovalent exchangeable cations. The swelling of clay particles could result in total or partial blockage of the conducting pores (Quirk and Schofield 1955). The importance of dispersion in soil permeability was recognised by Frenkel *et al.* (1978), Pupisky and Shainberg (1979) and Shainberg et al. (1981). Clay dispersion is highly sensitive even to low levels of sodicity and increases markedly at low ESP (Shainberg and Letey 1984). However, the importance and contribution of these mechanisms to the hydraulic properties of soils depend on the clay mineralogy at the species level, the ESP of the soil, the electrolyte concentration and the nature of electrolytes in the soil solution as reviewed by Gupta *et al.* (1990).

Smectites are the highly reactive group of clay minerals because of their very high specific surface area. Although soils containing all other clays swell with changes in moisture content, changes are particularly extreme in smectite (Borchardt 1989). Smectites are high swelling clays, especially when Na- saturated (Low, 1980). Smectites with low charge density swell more than smectites with high charge density (Alperovitch *et*

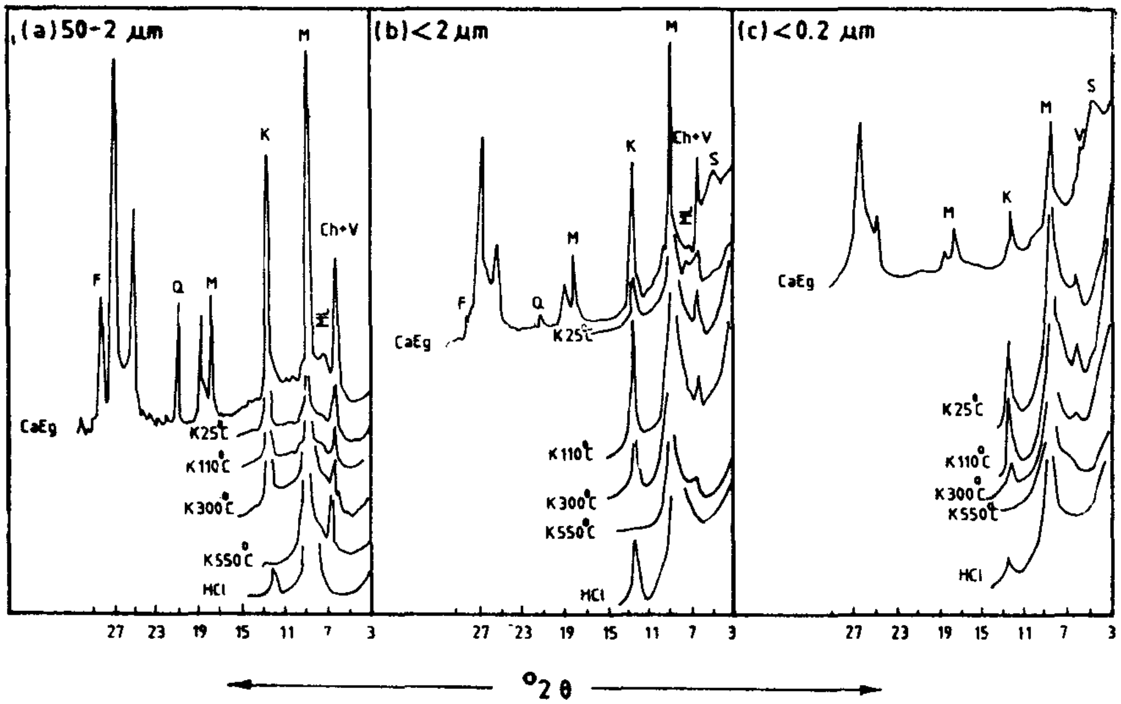

Fig.2.Representative XRD diagrams of silt (a), total clay (b) and fine clay (c) fractions of alluvial soils: CaEg=Ca- saturated and glycolated, K25°/110°/300°/550°= K-saturated and heated, S=smectite, M=mica, V=vermiculite, K=kaolinite, Ch=chlorite, ML=mixed layer (10-14A°) minerals, Q-Quartz, F=feldspars.

al. 1956; Slade and Quirk, 1991). Both the soils under study have smectite but it has low charge in Sodic Haplusterts and high charge in Typic Natrustalfs. The former soils contain 491 g kg^{-1} of smectite whereas the latter only 46 g kg^{-1} in the soil control section. This suggests that the observed impairment of hydraulic properties of Sodic Haplusterts even at a low level of ESP is due to large amount of clay, fine clay in particular which is dominated by low charge smectite whereas similar impairment occurs at a much higher level of ESP (40-50) in Typic Natrustalf because of loamy texture and low CEC caused by very small amount of smectite. It suggests that soils which do not contain smectite may not have the problem of drainage even at an ESP higher than 50. Thus the study demonstrates the role of content and nature of smectite in fixing the lower limit of ESP in soils and also suggests that the current lower limit of 15 ESP of United States Salinity Laboratory is arbitary and tentative.

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