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Characterization of Some Vertisols of Different Agro-ecological Regions of India

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Abstract: Vertisols have the capacity to shrink and swell, inducing cracks and distinctive soil structure throughout the soil profile. In India they occur in various agro-ecological regions such as humid tropical (HT), sub-humid moist (SHM), sub-humid dry (SHD), semi-arid moist (SAM), semi-arid dry (SAD) and arid dry (AD) climatic environments and thus indicate an array of soils in a climosequence. In this study benchmark Vertisols, series Panjari is from sub-humid (dry), Kheri is from sub-humid (moist) region, Teligi and Akola series are from semi-arid (dry) and Nimone is from arid agro-ecological region. All the Vertisols in general are characterized by dark colour, angular to sub-angular blocky structure, clay in texture and calcareous. These soils have high bulk density and high water retention capacity. These soils have deep, wide-opened desiccation cracks at the surface which extend deep into the profiles and the depth of cracks increases with aridity. Soils of all climates are dominated by Ca^{2+} ion on their exchange complex throughout the depth. However, in the sub-humid climate, Mg^{2+} ions tends to dominate in the lower horizons, whereas the semi-arid dry (Akola) soils have high Na^{+} ions in their exchange complex. The soils are slightly alkaline to strongly alkaline in nature and poor in organic matter. The CEC varied from 59.3 to 68.2cmol (p^{+}) kg^{-1} in soil of Panjari series followed by Teligi series profile. The calcium carbonate ($CaCO_3$) shows gradual increase with depth in all the soil profiles, though it is preferentially accumulated in the sub-surface horizons of lower rainfall region soils.In climosequence, the soils of the sub-humid region are generally Typic Haplusterts, soils of semi-arid region are Typic /Sodic /Calcic Haplusterts and soils of arid region are Sodic / Calcic / Aridic Haplusterts. The present study demonstrates how the soil properties of Vertisols in a different climate may help in inferring the change in climate in a geologic period.

Keywords : *Vertisols, agro-ecological regions, characterization*

Introduction

The cracking clay soils (Vertisols) occur in wider climatic zones of the world (Ahmad 1996). Dudal and Eswaran (1988) stated that Vertisols show characteristics that are related to overall climate. They also pointed out that other factors such as texture, clay mineralogy, the nature of cation saturation, and the amount of exchangeable sodium have equally important influence soil morphology and therefore, a correlation with climate appears to be somewhat complicated. However, Eswaran *et al.* (1988) suggested that the abundance of Vertisols in the semi-arid parts of the world apparently suggests the role of climate in their genesis.

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The majority of the Vertisols in India occur in the lower physiographic position *i.e.* in the lower piedmont plains or valleys (Pal and Deshpande 1987) or in micro depressions (Bhattacharyya *et al.* 1993). They are developed in the same parent material *i.e.* mainly in the alluvium of weathering Deccan basalt (Pal and Deshpande 1987; Bhattacharyya *et al.* 1993) mostly during the Holocene period (Pal *et al.* 2001, 2006). Vertisols exhibit cracks to the extent of >50 cm depth that are at least 1 cm wide and extent upward to the surface or the base of plough layer or surface crust. They are plastic and sticky when wet. Vertisols having 30% or more clay, gilgai micro-relief, slickensides and wedge shaped aggregates. (Blokhuis 1982; Wilding and Tessier 1988; Soil Survey Staff 2003).These soils are impoverished in organic carbon both in the surface and sub-surface layers (< 1 per cent) (Pal *et al.* 2009), indicating no substantial role of biotic factors in the formation of Vertisols in general and Sodic Vertisols in particular (Pal *et al.* 2003, 2009).

These soils have been developed in varied climatic zone resulting in variation in their properties and hence five Vertisols representing SHM, SHD, SAD, AD climates were characterized for their morphological and some physical, chemical characteristics and to classify the soils according to the USDA (Soil Survey Staff 2014).

Material and Methods

Five soil series were selected for the present study (Table 1).The profile representing each series was studied for their morphological properties. The characteristic of each pedon and its individual horizons were described following the procedure of the Soil Survey Manual (Soil Survey Staff 2005).The horizon-wise samples were collected and processed. Particle-size distribution was determined by International Pipette Method after removal of organic matter, $CaCO_3$ and Fe-oxides. Sand (2000-50 ì m), silt (50-2 ì m), total clay (<2 ì m), and fine clay (<0.2 ì m) fractions were separated according to the procedure of Jackson (1979). Bulk density was determined by the core method (Black 1965). Water retention was determined by pressure plate apparatus (Jackson 1973). After equilibrating the soil with distilled water in the ratio of 1:2 with occasional stirring for 30 min, the pH of the soil suspension was measured (Jackson 1958). EC was measured by using conductivity bridge (Jackson 1973). Cation exchange capacity (CEC) was determined by saturating the soil with1 *N* sodium acetate (pH 8.2) and exchanging the Na^+ ions in 1 *N* ammonium acetate (pH 7) (Richards 1954). The Na^+ ions were measured in atomic absorption spectrophotometer to calculate the CEC. Exchangeable Ca and Mg were determined following the 1 *N* NaCl solution extraction method and exchangeable Na and K were determined by 1 *N* NH_4OAc (pH 7) (Piper, 1966).

Table 1. Location, climatic condition and land use of soil series

Sr. No.	Location	Series	Climate	Land use
1	190 22' 0.02" N 740 39' 0.41" E	Nimone, Rahuri,Maharashtra	Arid	Cotton
2	210 01' 58.6" N 790 03' 29.4" E	Panjari,Nagpur, Maharashtra	Sub-humid dry	Cotton
3	200 41' 0.784" N 770 04' 0.011" E	Dr. P.D.K.V. Akola Research farm, Maharashtra	Semi-arid dry	Cotton
4	150 37' 0.622" N 760 54' 0.840" E	Teligi, Bellary,Karnataka	Semi-arid dry	Rice-wheat
5	230 14' 0.023" N 790 56' 0.609" E	Kheri, Jabalpur, Madhya Pradesh	Sub-humid moist	Wheat

$CaCO_3$ was determined by rapid titration (Piper 1966). Organic carbon was determined by Walkley and Black rapid titration method (Jackson 1973).

Results and Discussion

Vertisols of SHM and SHD

The area under SHM is characterized by MAR of 1134 mm, MAT of 26.9^0 C, MTw of 27.3^{0}C and MTd of 26.7^0 C. the area under SHD is characterized by MAR of 1071 mm, MAT of 27^0 C, MTw of 26.6^0 C and MTd of 23.3^{0}C. The soils of SHM occurring on very sloping lands are developed in the alluvium of the Deccan basalt whereas those of SHD climate in the alluvium of the Deccan basalt, granite-gneiss and limestone (Pal *et al.* 2009).

Soils of SHM climate are very dark grey to very dark greyish-brown, fine textured and > 150 cm thick. The surface horizons had moderate medium sub-angular blocky structures and were hard (dry) with friable consistency (moist). Strong, medium, sub-angular blocky structures with pressure faces and wedge-shaped aggregates and slickensides that break into small angular peds were prominent in the sub-soils (Table 2). The soils of SHD climate are very dark greyish-brown, fine textured and > 150 cm deep. The surface horizons had a medium sub-angular blocky structure with pressure faces and were friable. Strong, medium, sub angular blocky to weak sub angular blocky structure with pressure faces and weekly developed slickensides to strong medium angular blocky (weak) structure with weakly developed wedge-shaped aggregates and slickensides that break into weak angular peds were pre-dominant in the sub-soils (Pal *et al.* 2009).The soils of SHM and SHD climates have cracks of width 1-2 cm, extending upto 25-35 cm.

The bulk density is high in SHM climate as compared to SHD climate. Sand content is <10 per cent in SHD climate and <20 per cent in SHM climate. Clay content was higher which varied from 55 to 69 per cent in soils of SHD than those of under SHM climate (44-54%) (Table 3). The soil groups show >8 per cent clay increase in the Bss horizons than their Ap horizon. The ratio of FC/TC in the Bss horizons is greater than 1.2 times than the ratio in the Ap horizon (Table 2). The trends suggest an increase of clay in the Bss horizons due to the illuviation of clay (Soil Survey Staff 2003).

The pH of SHM and SHD climates ranges from neutral to slightly alkaline (6.9 – 8.4) whereas in other climates it ranges from slightly alkaline to strongly alkaline (8.2 – 9.2). The $CaCO_3$ content in soils of SHM and SHD climate is less than 14 per cent whereas, those of SHD are highly calcareous due to $CaCO_3$rich parent material. The $CaCO_3$ content increased with depth in both the soils. The CEC of SHD climate is higher than those of SHM climate (Pal *et al.* 2009). The SOC is higher in the surface of SHM soil as compared to SHD soil. The organic carbon in soil decreased with depth. Calcium and magnesium ion dominate the exchange complex in both the soil (Pal *et al.* 2009). The ESP of these soils is very low less than 3 per cent (Table 4).

Vertisols of SAD and AD environment

The area under SAD is characterized by MAR 764 mm, MAT of 25.9^0, MTw of 26.3^{0}C and MTd of 25.5^{0}C and the area under AD is characterized by MAR of 533 mm, MAT of 26.7^{0}C MTw of 28.2^{0}C and MTd of 26.2^{0}C. Both SAD and AD Vertisols occur on very gently sloping land developed on the alluvium of the Deccan basalt and granite-gneiss (Pal *et al.*, 2009).

The soils of SAD area were very dark grey to very dark greyish brown, fine textured and > 150 cm deep. The surface horizon had a moderate to strong, medium to coarse sub-angular blocky structures and was friable when moist. Strong, medium to coarse, angular blocky structure with slickensides and wedge-shaped aggregates that break into small angular peds and firm to very firm consistency when moist, was prominent in the sub-soils (Table 2). The soils have cracks of about 125 cm in SAD climate. The soils of AD are very dark greyish-brown to dark brown in colour, fine textured and >150 cm deep. The surface horizon had moderate to strong, medium to course sub-angular blocky structures with wedge-shaped aggregates and slickensides are prominent in the sub-soils (Table 2). The soils have wide cracks of 0.5-3.0 cm and extending to 125 cm depth.

The bulk density (1.4 - 1.8Mg m^{-3}) of SAD soils ishigh as compared to AD soil (1.3 – 1.4 Mg m^{-3}). In general, the soils of SAD and AD climate have <10 per cent sand and the clay content is more than 40 per cent (Table 3). Both SAD and AD soils in general indicated enrichment of clay in Bss horizon which is likely due to the illuviation process (Soil Survey Staff 2003).

Table 2. Morphological properties of the soils

Horizon	Depth (cm)	Boundary D T	Matrix Colour dry	Matrix Colour moist	Texture	Coarse Fragments	Structure S G TY	Consistence D M W	Porosity S Q	Nodules Q S	Roots S Q	Efferv. dil. HCL	Slickensides (p.f.)
Nimone series, Rahuri, Maharashtra (Very- fine smectitic isohyperthermic Sodic Haplusterts)													
Ap	0 - 15	c s	7.5YR 3/3	7.5YR 3/3	c	2-Jan	m 3 sbk	vhfrsp	f c	vf, c	vf, mf	es	-
Bw1	15 - 31	c s	-	7.5YR 2.5/2	c	1–2	m 3 sbk	vhfrsp	-	vf, c	vf,f c/m f	es	pf
Bw2	31 -61	g s	-	7.5YR 2.5/2	c	1–2	m 3 abk	- frsp	-	vf, c	vf,fcf	es	slk
Bss1	61 - 98	g s	-	7.5YR 2.5/2	c	3–4	m 3 abk	- frvsvp	-	vf, c	vf, f	es	slk
Bss2	98 - 127	c s	-	7.5YR 2.5/2	c	3–4	m 3 abk	- frvsvp	-	vfm fc	vf f	es	slk
Bss3	127 - 157	c s	-	7.5YR 2.5/2	c	5–8	m 2 abk	- frvsvp	-	vf, f /m, c f	vf f	ev	slk
Panjari series, Nagpur, Maharashtra (Very- fine smectitic hyperthemic Typic Haplusterts)													
Ap	0 - 19	c s	-	10YR 4/2	c	1–2	m 2 sbk	h frsp	f m	f,m, cf	vf f	1	-
Bw	19 - 38	g s	-	10YR 3/2	c	1–2	m 2 sbk	- frsp	-	f,m, cf	f fff	1	pf
Bss1	38 - 55	g s	-	10YR 3/3	c	1–2	m 2 sbk	- frsp	-	f, c	-	1	ss
Bss2	55 - 88	g s	-	10YR 3/3	c	1–2	m 2 abk	- fi sp	-	f, c	-	1	ss
Bss3	88 - 119	g s	-	10YR 4/2	c	2–3	m 2 abk	- fi sp	-	f, c	-	1	ss
Bss4	119 - 150		-	10YR 4/4	c	2–3	m 2 abk	- fi sp	-	f, m	-	1	ss
P.D.K.V. farm, Akola, Maharashtra (Very - fine smectitic hyperthermic Typic Haplusterts)													
Ap	0 - 11	c s	10YR3/2	10YR3/1.5	c	-	m 1/2 sbk	h frvsvp	vf, f c	vff,m f	vf f c	e	-
Bw1	11-26	c s	10YR3/2	10YR3/3	c	-	m 3 sbk	h frvsvp	vf, f c	vff,m f	vf c	e	pf
Bw2	26 - 46	c s	10YR3/2	10YR3/3	c	-	m 3 sbk	vhfr/fi vsvp	vf, f	vf f c	vf c	es	pf
Bss1	46 - 73	g s	7.5YR3/1	7.5YR3/2	c	-	m/c 3 abk	vhfr/fi vsvp	vf, f	vf f c	vf f	es	ss
Bss2	73 - 101	g s	7.5YR3/2	7.5YR3/2	c	-	m 3 abk	vhfr/fi vsvp	-	vf f c	vf f	es	ss
Bss3	101 - 119	g s		7.5YR3/2	c	-	m 3 abk	vhfr/fi vsvp	-	f m c	-	es	ss
Cr	119 - 150	c s		10YR4/2		-	massive			f m m	-	ev	

Horizon	Depth (cm)	Boundary D	Boundary T	Matrix Colour dry	Matrix Colour moist	Texture	Coarse Fragments	Structure S G TY	Consistence D M W	Porosity S Q	Nodules Q S	Roots S Q	Efferv. Dil Hcl	Slickensides (p.f.)
Teligi series, Bellary, Karnataka (Fine smectitic, isohyperthermic Sodic Haplusterts)														
Ap	0-10	c	s	-	10YR3/1		-	c 3 sbk	vhfrsp	f, vf m		vf, f c	es	-
Bw1	10-29	c	s	-	10YR3/1	c	-	c 3 sbk	vhfrvsvp	f, m	vf, f	vf, f c f	es	pf
Bw2	29-55	g	s	-	10YR2.5/1	c	-	m 3 sbk	- sfivsvp	vf m	vf, c	vf, f	es	pf
Bss1	55-81	g	s	-	10YR2.5/1	c	-	c 3 abk	- frvsvp	-	vf, f c	vf, f	es	ss
Bss2	81-107	g	s	-	10YR3/1	c	-	c/m 3 abk	- frvsvp	-	vf, fm m	vf, f	es	ss
Bw3	107-134	a	w	-	10YR3/2	c	-	m 3 abk	- frvsvp	-	f, f m	vf, f	es	pf(weak)
CrK	134-157				10YR5/3	gc	-	Massive	fr s po		vffm m		ev	
Soil is partially mixed with underlying saprolite, Cracks 10-12 cm wide upto 10 cm, 3-5 cm wide upto 30 cm and <1 cm wide upto 45 cm														
Kheri series, Jabalpur, Madhya Pradesh (Very-fine smectitic, hyperthermic Typic Haplusterts)														
Ap	0-9	c	s	10YR 4/2	10YR 4/2	c	fg, 1-2	m 1 sbk	shfrsp	-	-	vffmcf	-	-
Bw1	9-30	c	s	-	10YR 3/2	c	fg, <1	m 1/2 sbk	- frsp - f	-	-	vffmcf	-	-
Bw2	30-49	g	s	-	10YR 3/3	c	fg, 1-2	m 2 abk	vsvp - f	-	-	vffm f/c	-	pf
Bss1	49-76	g	s	-	10YR 3/2	c	fg, <1	m 3 abk	vsvp - f	-	-	vffm f/c	-	ss
Bss2	76-110	g	s	-	10YR 3/2	c	fg, <1	m 3 sbk	vsvp - f	-	-	vffm f/c	-	ss
Bss3	110-141	c	s	-	10YR 4/2	c	fg, 1-2	m 3 sbk	vsvp - f	-	-	vf f f	e	ss
Cr	141+				10YR 4/4	c	fg 3-5	m 2 sbk	spo	-	-	-	es	

Table 3. Physical properties of soils

Depth	BD (Mg m^{-3})	Water retention (%)		AWC	Sand	Silt	Total clay	Fine clay	FC/TC
		33 kPa	1500 kPa			(%)			
Nimone Series, Rahuri, Maharashtra									
0-15	1.4	36	25	11	4.0	29.6	66.4	46.0	0.69
15-31	1.4	37	26	11	4.0	28.3	67.7	48.7	0.72
31-61	1.4	40	32	8	4.2	29.7	66.1	47.2	0.71
61-98	1.3	43	30	13	4.5	26.2	69.3	50.2	0.72
98-127	1.4	44	33	11	2.7	26.6	70.7	52.4	0.74
127-157	1.3	48	34	14	2.7	26.8	70.5	53.2	0.75
Panjari Series, Nagpur, Maharashtra									
0-19	1.5	38	28	10	0.6	44.0	55.4	42.0	0.76
19-38	1.6	35	26	9	0.4	42.1	57.5	49.5	0.86
38-55	1.4	33	27	6	0.3	31.7	68.0	53.0	0.78
55-88	1.5	35	29	6	0.3	32.5	67.2	54.3	0.81
88-119	1.4	38	30	8	0.3	43.7	56.0	49.2	0.88
119-150	1.5	38	25	13	0.2	31.2	68.6	54.0	0.79
P.D.K.V. farm, Akola, Maharashtra									
0-11	1.4	36	22	14	3.8	39.7	56.5	36.3	0.64
11-26	1.7	34	23	11	3.6	29.8	66.6	29.0	0.44
26-46	1.7	35	23	12	3.5	44.9	51.6	18.0	0.35
46-73	1.7	41	25	16	2.5	50.2	47.3	20.4	0.43
73-101	1.5	43	27	16	3.7	56.0	40.3	27.4	0.68
101-119	1.7	44	29	15	4.8	51.5	43.7	24.9	0.57
119+	1.7	39	25	14	4.2	53.6	42.2	22.3	0.53
Teligi Series, Bellary, Karnataka									
0-10	1.7	33	25	8	10.1	20.7	69.2	33.0	0.48
10-29	1.7	34	23	11	9.1	29.8	61.1	43.8	0.72
29-55	1.8	33	22	11	7.9	24.4	67.7	56.9	0.84
55-81	1.8	33	15	18	7.8	21.9	70.3	42.0	0.60
81-107	1.7	39	16	23	7.4	18.8	73.8	44.7	0.61
107-134	1.7	46	20	26	6.3	23.7	70.0	47.0	0.67
134-157	1.7	24	11	13	3.7	27.9	68.4	44.4	0.65
Kheri Series, Jabalpur, Madhya Pradesh									
0-9	1.6	35	18	17	18.4	30.5	51.1	27.3	0.53
9-30	1.8	35	17	18	16.6	29.7	53.7	32.2	0.60
30-49	1.9	35	17	18	16.8	36.9	46.3	31.0	0.67
49-76	1.8	35	17	18	6.0	40.4	53.6	28.7	0.54
76-110	1.9	39	19	20	14.8	38.6	46.6	33.7	0.72
110-141	1.9	39	19	20	16.4	39.0	44.6	27.0	0.61
141+	1.9	36	17	19	15.9	37.4	46.7	34.8	0.75

Table 4. Chemical properties of soils

Depth	pH	EC (dSm^{-1})	$CaCO_3$ (%)	OC (%)	CEC {cmol $(p+)kg^{-1}$}	Extractable bases Ca	Mg	Na	K	sum	ESP (%)	Ca/Mg ratio
Nimone series, Rahuri, Maharashtra												
0-15	8.3	0.17	11.6	0.90	48.6	29.7	9.3	1.5	0.72	41.2	4	3.2
15-31	8.4	0.14	12.5	0.82	47.5	29.5	9.2	1.9	0.66	41.3	5	3.2
31-61	8.4	0.11	13.0	0.68	47.8	29.3	10.1	2.4	0.48	42.3	6	2.9
61-98	8.4	0.10	14.3	0.64	47.7	29.6	9.93	2.5	0.49	42.5	6	3.0
98-127	8.4	0.08	15.5	0.56	47.3	29	11.3	3.1	0.53	43.9	7	2.6
127-157	8.4	0.08	16.5	0.49	42.5	25.1	11.6	3.5	0.56	40.8	9	2.2
Panjari series. Nagpur, Maharashtra												
0-19	8.2	0.18	9.0	0.78	65.1	44.1	8.7	0.9	0.93	54.6	2	5.1
19-38	8.2	0.13	10.0	0.62	64.6	50.1	8.38	0.7	0.53	59.7	1	6.0
38-55	8.3	0.16	11.0	0.54	59.3	45.3	8.21	0.9	0.42	54.8	2	5.5
55-88	8.3	0.15	11.5	0.53	64.7	48.6	9.11	0.9	0.47	59.1	2	5.3
88-119	8.3	0.16	13.3	0.48	68.2	51.23	11.08	1.1	0.51	63.9	2	4.6
119-150	8.3	0.18	14.0	0.40	68.1	49.93	10.94	1.3	0.52	62.7	2	4.6
P.D.K.V. farm, Akola, Maharashtra												
0-11	8.2	0.31	7.2	0.74	55.9	37.9	7.2	0.9	1.22	47.2	2	5.3
11-26	8.2	0.33	7.2	0.67	55.1	36.1	7.9	0.8	0.85	45.7	2	4.6
26-46	8.8	0.30	8.9	0.59	57.6	35.3	10	1	0.56	46.9	2	3.5
46-73	9.1	0.36	9.8	0.56	55.9	37.6	10.8	1.1	0.35	49.9	2	3.5
73-101	9.0	0.25	16.3	0.54	44.7	32.1	8	1.2	0.37	41.7	3	4.0
101-119	9.0	0.41	17.5	0.48	46.5	31.6	8.2	1.4	0.45	41.7	3	3.9
119+	8.9	0.33	20.8	0.23	47.6	29.3	8.9	2.1	0.53	40.9	5	3.3
Teligi series, Bellary, Karnataka												
0-10	8.2	0.31	7.5	1.57	45.1	28.9	5.3	2.0	0.8	37.0	5	5.5
10-29	8.3	0.22	8.2	1.18	43.2	31.2	6.9	2.3	0.9	41.3	6	4.5
29-55	8.6	0.22	12.5	0.83	41.2	28.6	7.5	2.4	0.7	39.1	6	3.8
55-81	8.3	0.22	15.4	0.79	40.8	27.5	7.0	2.5	0.6	37.6	7	3.9
81-107	8.7	0.26	19.2	0.66	39.8	27.1	6.7	2.6	0.4	36.8	7	4.0
107-134	8.7	0.37	22.8	0.60	41.2	27.6	6.2	2.6	0.4	36.7	7	4.5
134-157	9.2	0.24	30.5	0.31	40.2	27.3	5.7	2.9	0.4	36.3	8	4.8
Kheri series, Jabalpur, Madhya Pradesh												
0-9	6.9	0.17	4.3	1.34	42.2	33.4	5.2	0.6	0.54	39.7	2	5.7
9-30	8.0	0.10	4.5	0.46	41.3	34.9	4.9	0.6	0.42	40.8	1	5.9
30-49	8.1	0.10	5.0	0.42	41.1	35.1	5.1	0.7	0.36	41.3	2	5.5
49-76	8.2	0.12	6.5	0.39	40.8	35.9	6.3	0.9	0.38	43.5	2	4.4
76-110	8.2	0.07	7.5	0.35	39.5	36.1	7.2	0.9	0.38	44.6	2	3.6
110-141	7.9	0.13	11.3	0.31	39.2	35.6	7.7	1.1	0.39	44.8	2	3.3
141+	8.4	0.19	13.0	0.25	38.2	36.6	7.6	1.3	0.37	45.9	3	3.2

The Vertisols of SAD and AD climates are alkaline and calcareous. The $CaCO_3$in both the soils increased with depth. This indicates that with lowering of MAR the water loss through evapotranspiration is a primary mechanism in the precipitation of $CaCO_3$ and high temperature as an additional factor plays an important role in controlling the water flow in the soil profile, which is responsible for formation of soils more alkaline and calcareous (Rabenhorst *et al.* 1984; Pal *et al.* 2009). Organic carbon content was higher in surface and decreased with depth in SAD and AD soils. In general, the organic carbon content was higher in SHM and SHD soils. Calcium plus magnesium dominate the exchange complex (Pal *et al.* 2009). The ESP was highest in AD soils followed SAD, SHM and SHD (Table 4). This trend suggests that the aridity in the climate is the prime factor in the formation of sodic soils (Pal *et al.* 2000; Pal *et al.* 2009).

Conclusion

It is concluded that in Indian sub-continent, Vertisols in sub-humid moist, sub-humid dry, semi-arid dry and arid dry climatic environment occur in a climosequence as evidenced from their morphological, physical and chemical properties. Alteration in soil properties in the climosequence resulted in the formation of different types of Vertisols (Typic Haplusterts and Sodic Haplusterts). The differential properties of Vertisols in a climosequence suggest that the cropping pattern/ cropping sequence and management practices would vary with changing climatic environment and that study of soils is necessary for advocating policy decision in different agro-climatic zones.

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